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SIXTH UNITED NATIONS REGIONAL
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New York, 2-6 June 1997
Item 5 (a) of the provisional agenda*

REVIEW OF THE LATEST TECHNOLOGY IN CARTOGRAPHIC DATA ACQUISITION, MANIPULATION, STORAGE AND PRESENTATION, WITH SPECIAL EMPHASIS ON POTENTIAL APPLICATIONS IN DEVELOPING COUNTRIES: AUTOMATED MAPPING PROJECTS: DEVELOPMENT AND APPLICATION OF DIGITAL CARTOGRAPHIC DATABASES, INCLUDING DIGITAL TERRAIN MODELLING

Designing a new National Atlas of the United States

Paper submitted by the United States of America**

* E/CONF.90/1.

** Prepared by Stephen C. Guptill, United States Geological Survey.

97-09947 (E) 080597

INTRODUCTION

The U.S. Geological Survey (USGS) and other agencies of the Federal Government have amassed a large volume of earth science and other geospatial data, but these data sets are not easily accessible and useable together. The *National Atlas* provides a mechanism to bring diverse national-level data sets together in a way that has not been done before. The project depends on the participation of nongovernmental partners to provide consumer-level geographic information system (GIS) software, assistance with publication formats and marketing strategies, and development of widespread sales and distribution networks.

PRODUCT DESIGN

The *National Atlas* project will use GIS technology to bind together diverse sets of geospatial information into definitive information resources and to furnish uniform access capabilities to display and analyze the data. *National Atlas* products would use GIS data viewing and analysis tools combined with definitive sets of geographic reference, thematic, and statistical data to provide users with the capability to make their own maps. Users will have the flexibility to select, combine, symbolize, and display the data sets of interest to them. Printed maps of visually interesting and relatively stable subject matter (for example, image map of the United States, shaded relief, land cover, surficial geology, roads, drainage and political boundaries) may be sold separately or bundled with CD-ROM products. In addition, Internet access to USGS data sets would allow users to get the latest information on earthquakes, stream flow rates, and other events where knowledge is time-sensitive. World Wide Web (WWW) pages would describe atlas content, provide graphic examples, and enable electronic ordering.

A successful public and private partnership will enable the *National Atlas* project to provide two key outputs:

> A set of integrated, consistent, and authoritative data that can be used to answer a wide variety of questions regarding the physical and societal conditions of the Nation. These data will be conveyed to the users through various media, including CD-ROM's, WWW pages, and printed maps.
>
> A geographic information system tool that can be used to display and analyze a wide variety of geospatial data. The provision of this standard tool will encourage other data producers to take advantage of its capabilities and to offer their data in a form that can be used with the existing national level data sets or with sets of regional or site-specific data.

A key feature of the *National Atlas* is that the data sets will be processed so that different themes of information can be combined, displayed, and analyzed together. This requires that the data are geographically registered to the same coordinate system, are of comparable spatial resolutions, and are logically consistent. Many of the desirable data sets exist in digital form but need further processing to ensure consistency between data sets. The data sets to be provided by the USGS include the following types of information relating to:

highway systems (with route numbers)
rail systems
river systems (with names)
populated places
Federal lands
elevation (relief)
land cover and land surface images
sea floor images (Exclusive Economic Zone)
surficial and bedrock geology
mineral occurrences
organic fuels
geophysics
land forms
geochemistry
faults and historic seismicity
marine and sea floor characteristics
coastal erosion
surface and ground water
water use and quality

In addition, major sets of geospatial data will be obtained through partnerships with other Federal agencies, including the following:

Department of the Interior (public lands, wetlands data)
National Oceanic and Atmospheric Administration (climate and geophysical data)
Environmental Protection Agency (environmental data)
Bureau of Transportation Statistics (roads, railroads)
Department of Agriculture (soils, forest data)
Bureau of the Census (political boundaries, Congressional districts, socioeconomic, agricultural, and demographic data)
Bureau of Labor Statistics (economic data)
Other agencies that collect relevant statistical data

The first planned product will be a CD-ROM containing various digital data sets linked to the GIS software. Information from the Internet and printed maps will follow. After the first release, subsequent CD-ROM and printed folio editions will include newly available data sets. Editions based on States or national regions are also possible.

USER NEEDS

The *National Atlas* project addresses the needs of three user communities: the educational sector, the general public, and the public policy sector. Specific products and groups of products can be tailored and targeted for several markets. The potential for outreach into the educational sector is great. In addition to being available in public and school libraries, the data and GIS capabilities could be used in geography curricula in K-12 classrooms to meet the National Geography Standards. Success in the educational sector would augur well for success in marketing to the reference work segment of the general public. The geographically referenced earth science and statistical data, available for display and manipulation in the *National Atlas*, would support informed public policy decision making. Widespread use of *National Atlas* products by those in the public policy field would create an influential constituency for project support.

PRODUCTION REQUIREMENTS

The USGS has two unique capabilities that complement the expertise of private sector partners in the production of the *National Atlas*:

Provider of credible data sets - Data provided in the *National Atlas* should be authoritative; this is difficult for a private sector firm to achieve without close collaboration with the appropriate government authorities. The USGS will act as a "data consolidator" in arranging cooperative agreements with other government agencies for data on a certain theme; it will ensure that the data sets are appropriate for that theme and can be used with related data. The USGS is in a unique position to perform this data collection, evaluation, and integration.

Expertise in GIS and digital cartography - The project will require personnel skilled in creating GIS applications software, in developing digital data bases related to their disciplines, and in knowing how these data can be combined. Likewise, it will require experts in the appropriate scientific methods needed to analyze the data sets. Also needed will be experts in the cartographic display of the data sets. The USGS has personnel with these various skills, thus enabling private firms to bring more innovative technology and richer data sets to the market in a shorter timeframe.

The project depends on nongovernmental partners to provide user-friendly GIS software, to assist with publication formats and marketing strategies, and to develop a widespread sales and distribution network. Private sector skills in identifying specific target markets and developing appropriate products are key facets of this program.

Marketable products are expected as early as May 1998. The dates and nature of the initial products will be the subject of analysis and negotiation between the USGS and the private sector firms. Subsequent editions are planned to incorporate more comprehensive data sets and (or) GIS technology. State or regional editions, incorporating more detailed spatial data, are possible as part of an expanded product line.

PROTOTYPE DESIGN

The USGS has developed a working prototype of the electronic *National Atlas*. The prototype uses a simple user interface to select and manipulate a sampling of national data sets. Work on the prototype has enabled us to gain experience in developing the user interface, demonstrate to potential partners the functions envisioned for the atlas, begin integrating national digital data sets, develop preliminary design and functional specifications, and receive feedback from interested parties. Figure 1 shows the opening screen and pull-down menu bars. (The *National Atlas* displays are in color; the figures here are reduced in size and shown in black and white)

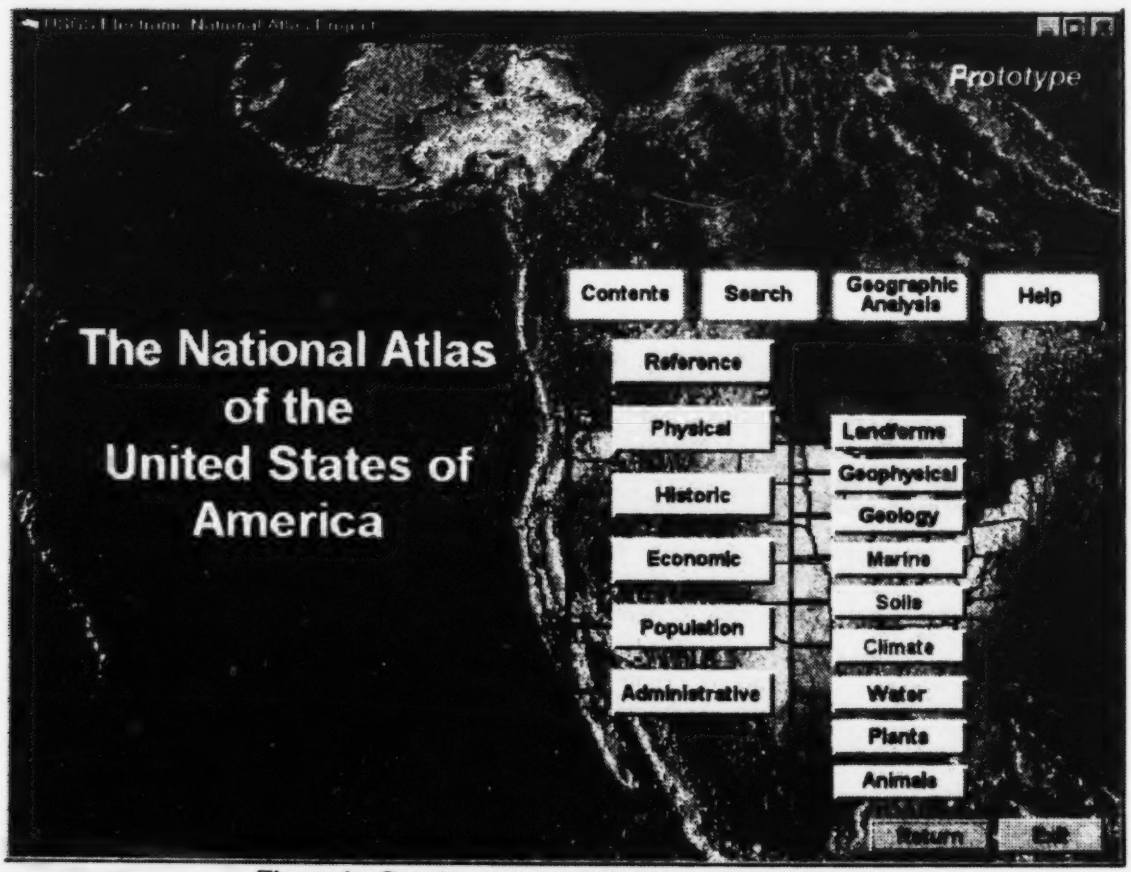

Figure 1. Opening screen of *National Atlas* prototype.

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Figure 2 shows descriptive text about one of the data themes (physical - fauna) and large choice buttons allowing the user to display map data and metadata, access a multimedia presentation, or link to the World Wide Web.

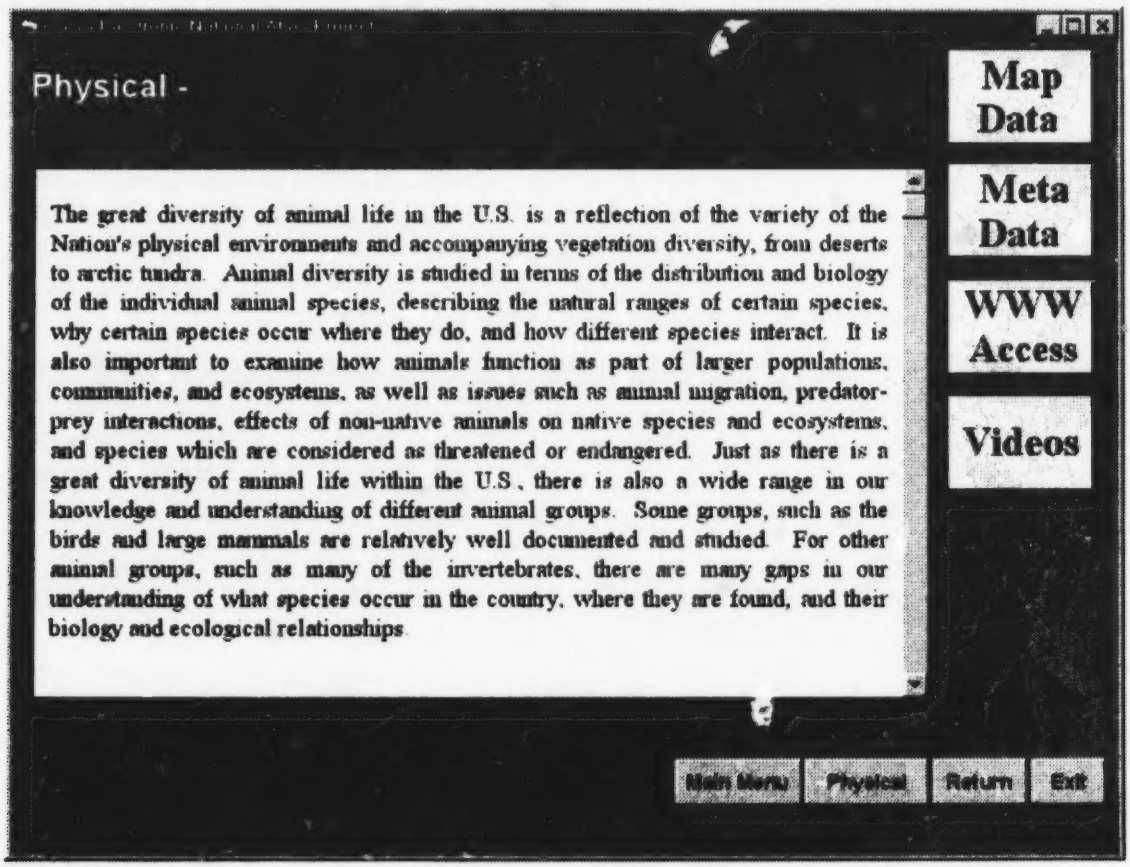
Physical -
Map Data
Meta Data
WWW Access
Videos
The great diversity of animal life in the U.S. is a reflection of the variety of the Nation's physical environments and accompanying vegetation diversity, from deserts to arctic tundra. Animal diversity is studied in terms of the distribution and biology of the individual animal species, describing the natural ranges of certain species, why certain species occur where they do, and how different species interact. It is also important to examine how animals function as part of larger populations, communities, and ecosystems, as well as issues such as animal migration, predator-prey interactions, effects of non-native animals on native species and ecosystems, and species which are considered as threatened or endangered. Just as there is a great diversity of animal life within the U.S., there is also a wide range in our knowledge and understanding of different animal groups. Some groups, such as the birds and large mammals are relatively well documented and studied. For other animal groups, such as many of the invertebrates, there are many gaps in our understanding of what species occur in the country, where they are found, and their biology and ecological relationships.
Main Menu
Physical
Return
Exit

Figure 2. Navigation of a data theme.

Figure 3 shows a simple map display including shaded relief, roads, lakes, and streams. Menu buttons along the top of the window allow the user to add more data and perform various specialized functions, such as overlay analysis and buffer generation.

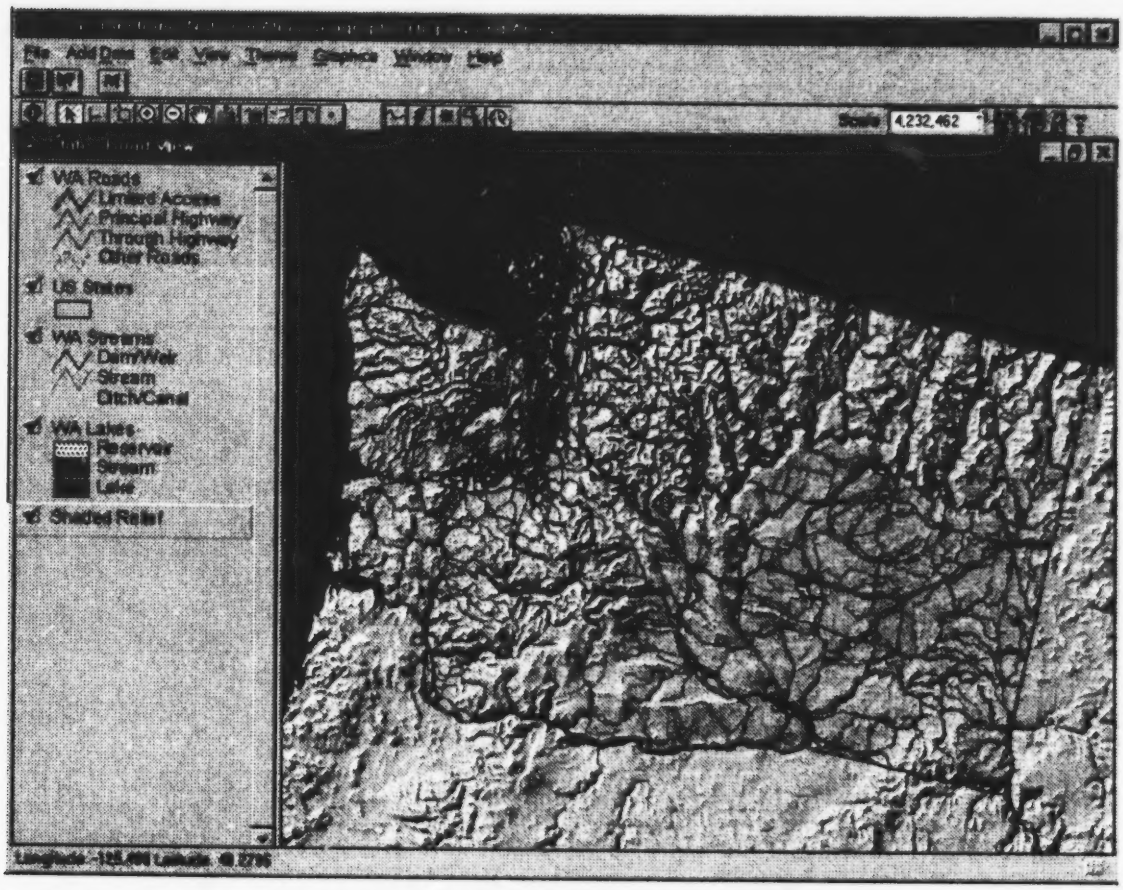

Figure 3. *National Atlas* map display.

Figure 4 shows the results of a query of a gazetteer containing about 2 million names. In addition to information about the characteristics of the named feature, a map showing its location is displayed.

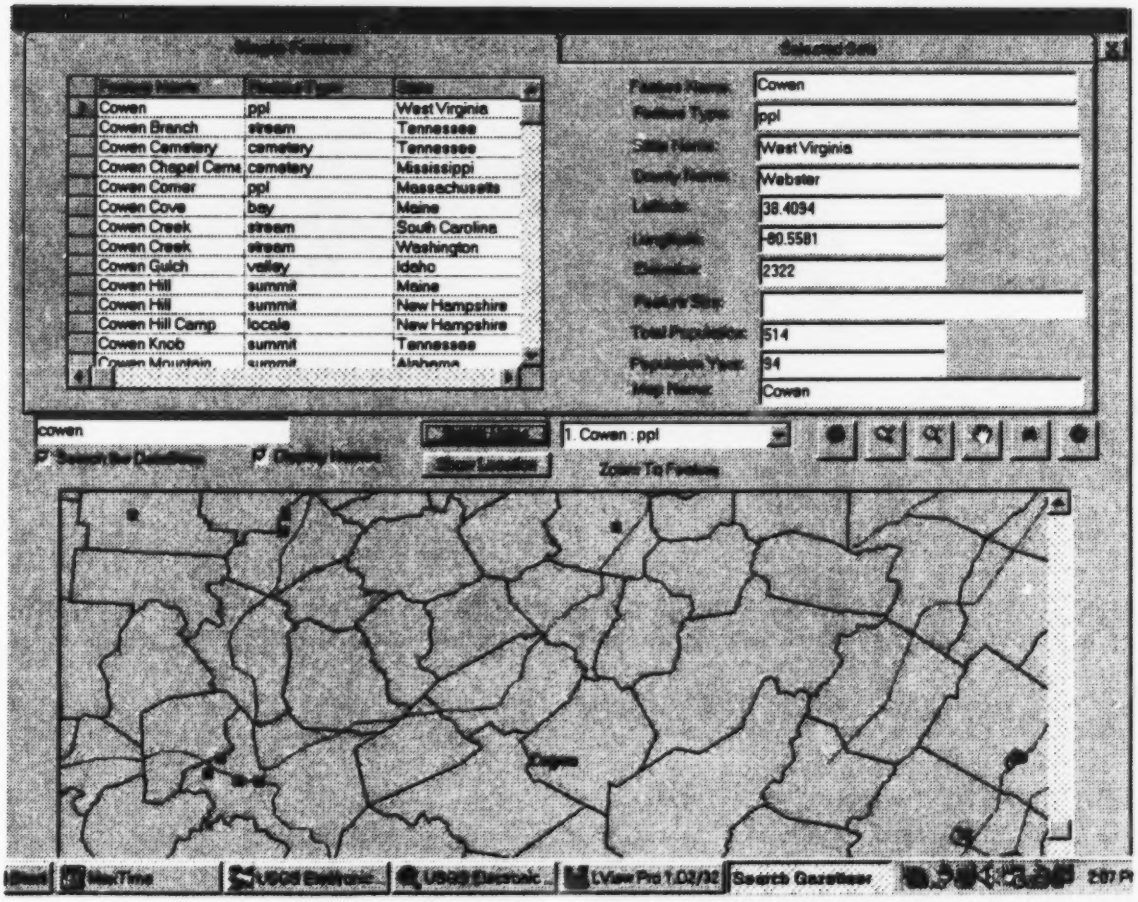

Figure 4. Results of gazetteer query.

Figure 5 shows a part of a data base for all of the national parks, with links to map data and WWW pages. The Internet link would allow users to find out information on the latest park activities and conditions.

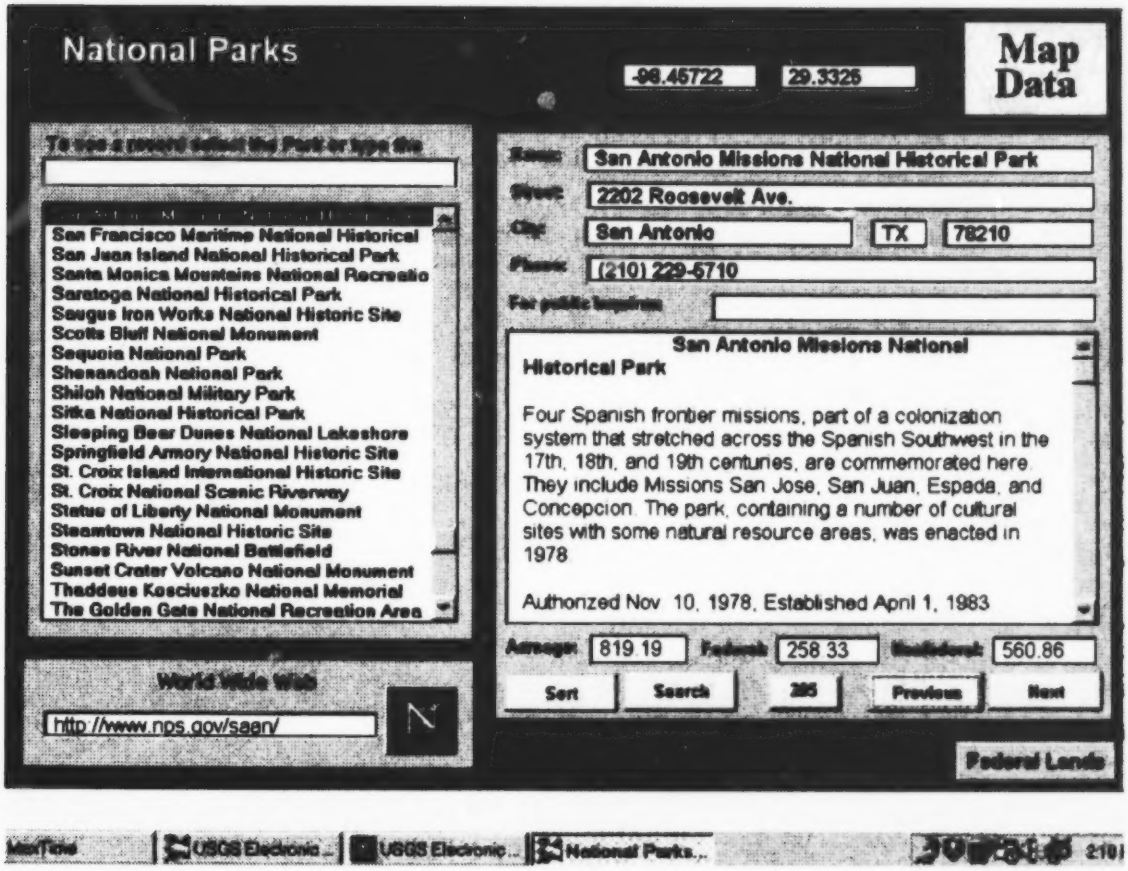
National Parks
-98.45722
29.3326
Map Data
San Francisco Maritime National Historical
San Juan Island National Historical Park
Santa Monica Mountains National Recreatio
Saratoga National Historical Park
Saugus Iron Works National Historic Site
Scotts Bluff National Monument
Sequoia National Park
Shenandoah National Park
Shiloh National Military Park
Sitka National Historical Park
Sleeping Bear Dunes National Lakeshore
Springfield Armory National Historic Site
St. Croix Island International Historic Site
St. Croix National Scenic Riverway
Statue of Liberty National Monument
Steamtown National Historic Site
Stones River National Battlefield
Sunset Crater Volcano National Monument
Thaddeus Kosciuszko National Memorial
The Golden Gate National Recreation Area
San Antonio Missions National Historical Park
2202 Roosevelt Ave.
San Antonio
TX
78210
(210) 229-5710
San Antonio Missions National
Historical Park
Four Spanish frontier missions, part of a colonization system that stretched across the Spanish Southwest in the 17th, 18th, and 19th centuries, are commemorated here. They include Missions San Jose, San Juan, Espada, and Concepcion. The park, containing a number of cultural sites with some natural resource areas, was enacted in 1978
Authorized Nov 10, 1978, Established April 1, 1983
819 19
258 33
560.86
Sort
Search
Previous
Next
Federal Lands
http://www.nps.gov/saan/
USGS Electronic...
USGS Electronic...
National Parks...

Figure 5. Query of a national parks data base.

The prototype is being used in a variety of customer evaluation and testing situations to help design a compelling product. In this version of the prototype, data sets are stored on CD-ROM and the application software runs on the local (client) machine. Internet capabilities allow the seamless

integration of more current or additional attribute information with that contained on the CD-ROM. Alternate designs, where more data and software functionality reside on network servers, also are being evaluated.

CONCLUSION

The *National Atlas* project provides a showcase for geospatial data and mapping technology. The project will increase awareness not only of the geospatial information collected and analyzed by the USGS and other agencies, but also of the use of GIS technology in the display and analysis of geographically referenced statistical data. The project will benefit from a synergistic relationship between the public and private sectors in the production of the *National Atlas*. The real beneficiaries will be the atlas users, who will be able to readily access and use large amounts of geospatial information about our country.

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Item 5 (g) of the provisional agenda*

REVIEW OF THE LATEST TECHNOLOGY IN CARTOGRAPHIC DATA ACQUISITION, MANIPULATION, STORAGE AND PRESENTATION, WITH SPECIAL EMPHASIS ON POTENTIAL APPLICATIONS IN DEVELOPING COUNTRIES: HYDROGRAPHIC SURVEYING AND NAUTICAL CHARTING

The Digital Nautical Chart: a multi-use database

Paper submitted by the United States of America**

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** Prepared by Captain J. E. Ayres, United States Navy (Retired), National Imagery and Mapping Agency.

97-09950 (E) 290497

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INTRODUCTION

The National Imagery and Mapping Agency (NIMA) is an agency of the Department of Defense(DoD), primarily charged to supply the accurate imagery, imagery intelligence, and global geospatial information required by the United States Army, Navy, Air Force, and Coast Guard. In addition, we are required by law to make available to the civil sector those of our products which enhance the safety of marine navigation. Our Defense mission has required us to provide products in a variety of paper and digital formats, often duplicating the information content to meet unique format requirements of the various systems being served. This situation is rapidly improving as we pursue the DoD goal of fully interoperable systems within and between the Services. We have standardized our raster and compressed raster data formats, and especially we have settled on a standard vector format for a wide variety of products.

That vector standard is called Vector Product Format, or VPF, and it is our implementation of the international Digest-C standard format adopted by NATO and some National Governments. Among our current or planned VPF outputs are a V-Map series of digital multipurpose data bases at scales from 1:1,000,000 to 1:15,000, littoral warfare data bases encompassing a region which could extend from 200 miles at sea to 60 miles inland, special submarine navigation products, and the navigational data bases which will replace paper nautical charts in the paperless ships of tomorrow's Navy. It is these navigational data bases which are the subject of this paper, for they hold the potential of serving coastal planning, environmental protection, transportation monitoring, and other civil efforts as well as safe navigation.

VPF is a relational data format, with data presented as topologically structured thematic layers. VPF and other formats in the DIGEST suite of standards rely on a Feature and Attribute Coding Catalog, the robust content of which supports nautical, aeronautical and topographic products alike. Because VPF is a relational data format, it is ideal for use in geographic information systems(GIS), where VPF data bases serve as versatile backdrops for the addition of purpose-specific information layers generated by the user. This can be illustrated by a discussion of our primary nautical chart product, the nautical navigational data base which we call the Digital Nautical Chart, or DNC.

The DNC is not only a comprehensive chart data base for ship navigation, it also is a component of other complex NIMA digital products such as the one for littoral warfare, and is designed to be integrated in combat systems with other VPF products. One way to do this integration, which avoids both translation loss and display confusion, is to have the combat system exploit the data directly in its VPF format. This approach is being taken by Navy and is expected to be implemented in some

civil GIS display equipments. This does not rule out translation into another format for data exploitation, since all VPF data bases should translate the same way, but it does give a useful option.

I am assuming that enough has been published on electronic charts in recent years to ensure that you all are familiar with the subject. I'll therefore keep the explanation of the DNC brief. With the exception of its format, the DNC has been developed to satisfy the standards set forth by the International Maritime Organization(IMO) and the International Hydrographic Organization (IHO) for the data bases to be used in their Electronic Chart Display and Information System(ECDIS) equipment. ECDIS is a very high-end replacement for the conventional paper chart to be used by the civil mariner. The IHO specifies a data format called S57 for delivery of data to an ECDIS. However, unlike VPF which is both a transfer and an operating format, S57 is a transfer format only--data cannot be held in it for direct exploitation within an ECDIS system. DNCs in VPF contain the same data content and functionality as their S57 counterparts. The data layers contained in the DNC as a seamless data base are shown in Figure 1. As can be seen from Figure 1, many of the themes layered are essential to those who plan or monitor coastal zone activities. Although such things as cultural landmarks, land cover, and relief may have sparse coverage in the DNC because only material relevant to safety of navigation is included, the coding catalog includes features and attributes to facilitate input of a broad range of user information under the categories, and standardized symbology for these additions exists for use on other NIMA products. The data basic to exploitation for coastal zone purposes, such as shoreline, islands, depths, bridges and so on are there, and are to the best accuracy available to us.

Our statutory commitment to the civil mariner is met through release for public sale of products for defense which enhance safety of navigation, and will be met by release of the DNC. This will make the DNC available not only to the mariner, of course, but also to those who require data bases of the geographic areas covered for other purposes.

Our production of DNCs is proceeding. We are dividing the world into 29 regions for CD-ROM purposes, as shown in Figure 2, and intend to digitize over 3700 charts to establish the full data base. Data bases are constructed by libraries which represent the scale ranges associated with general, coastal, approach and harbor charts, plus a browse library for orientation on DNC content. Tile size varies by library, as noted in Figure 1. Our NIMA production priorities place emphasis on U.S. ports and approaches, and Navy home ports overseas, in order to allow early practical training of Navy personnel as soon as their navigation display systems are installed aboard ship. We are also giving priority to support of special Navy projects as they arise. In addition,we are now in, or arranging, coproduction of VPF products with other nations, which will expedite the availability of the data bases. We should achieve worldwide DNC coverage by 1999. All DNC will be on WGS 84 datum, and show depths in meters.

We have a VPF updating method in an advanced state of development, and based on it will implement a DNC telecommunications based update service for Navy. Because of the lower data rates used in communications by much of the civil merchant marine, we still must consider what update service will be adequate for that sector. While updating is vital for navigation applications

of the DNC, it probably is a minor consideration for most GIS purposes. NIMA is also developing what we have termed Full Utility Navigation Demonstration, or FUND, software which we require to help familiarize our customers with the DNC, but which should actually exploit the DNC in operating systems to an estimated 95 percent or more of the capabilities for safe navigation, and be of use in GIS exploitation of the data base. The FUND software is currently UNIX based, but shortly will be available also in Windows NT for PC application.

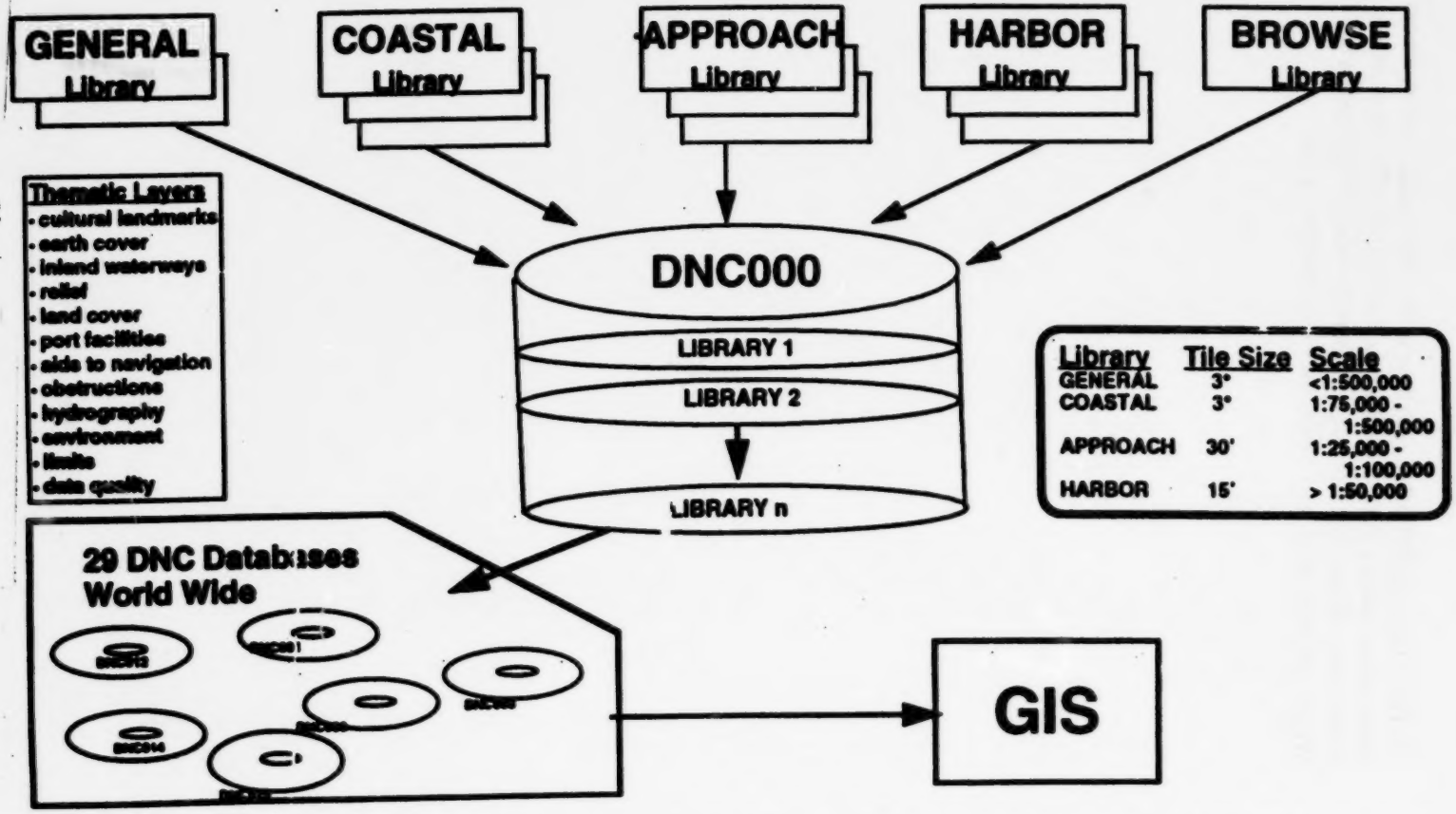
The DNC data base results from the digitization of charts from the NIMA portfolio. Many of these charts are based on data gleaned from foreign survey operations. The free use of foreign data in chartmaking has long been an established practice by many nations, as it was recognized that all benefited by increased availability of reliable charts. In recent years, however, the safety of navigation has taken a poor second place to the bottom line in the revenue ledger of several nations, and claims of copyright and intellectual property rights have been put forward in an attempt to obtain revenue for data used. While it has been the NIMA position that natural facts, whether the height of Mount Everest or the depth of the sea off Gibraltar, are not subject to copyright or intellectual property rights consideration, we do recognize that major resources and considerable personal effort go into the collection of chart data. We wish to avoid agreements which require administrative overhead which would probably far exceed the amount of royalty payments involved in the public sale of our charts based on foreign data, and we would not recognize any constraint on the use of NIMA products for U.S. Government purposes. But in the spirit of cooperation we would consider agreements to make available to the country whose survey data was used in our charts the VPF database which covered that country's national waters and coasts, and the international waters of its region, software to facilitate updating if the software rights are held by NIMA, and our FUND software to manipulate the data. The recipient country's Hydrographic Authority could repackage and sell the data for GIS purposes such as coastal or environmental planning or, if they implemented an updating service, for navigation. We believe that such an approach could relieve a number of small Hydrographic Offices from the necessity to spend the substantial resources required to produce a vector data set such as is now called for by the IHO, as well as result in a positive cash flow for them from the sale of the repackaged DNC products. We know from our own experience, as well as that of others, that many Hydrographic Authorities desiring compensation do not want that compensation in the form of royalties, since such royalties could go directly to their nation's treasury rather than to their operating fund. We expect many to prefer to receive the VPF data.

We do not expect to place our DNCs of foreign waters on public sale before we have discussed an appropriate quid pro quo with the affected nations. However, we have made our DNCs of United States waters available for GIS and navigational aid purposes, and those same DNCs will replace the paper chart for navigational use as soon as an adequate civil sector updating service can be developed. DNC use in lieu of the paper chart by the civil mariner requires that the U.S. Coast Guard authorize the use of the data base, with approved equipment, in US waters. A similar authorization by the appropriate maritime regulatory authority would be required for such civil maritime use of digital chart displays in the waters of other nations.

We know that our VPF DNC data base is the only feasible option for our Navy. We believe that our approach to making our DNC data base and related software available to other nations is not only in their best interests but also that it furthers the safety of navigation and facilitates national planning. We are proud to be able to contribute to the common good.

DNC Data Content

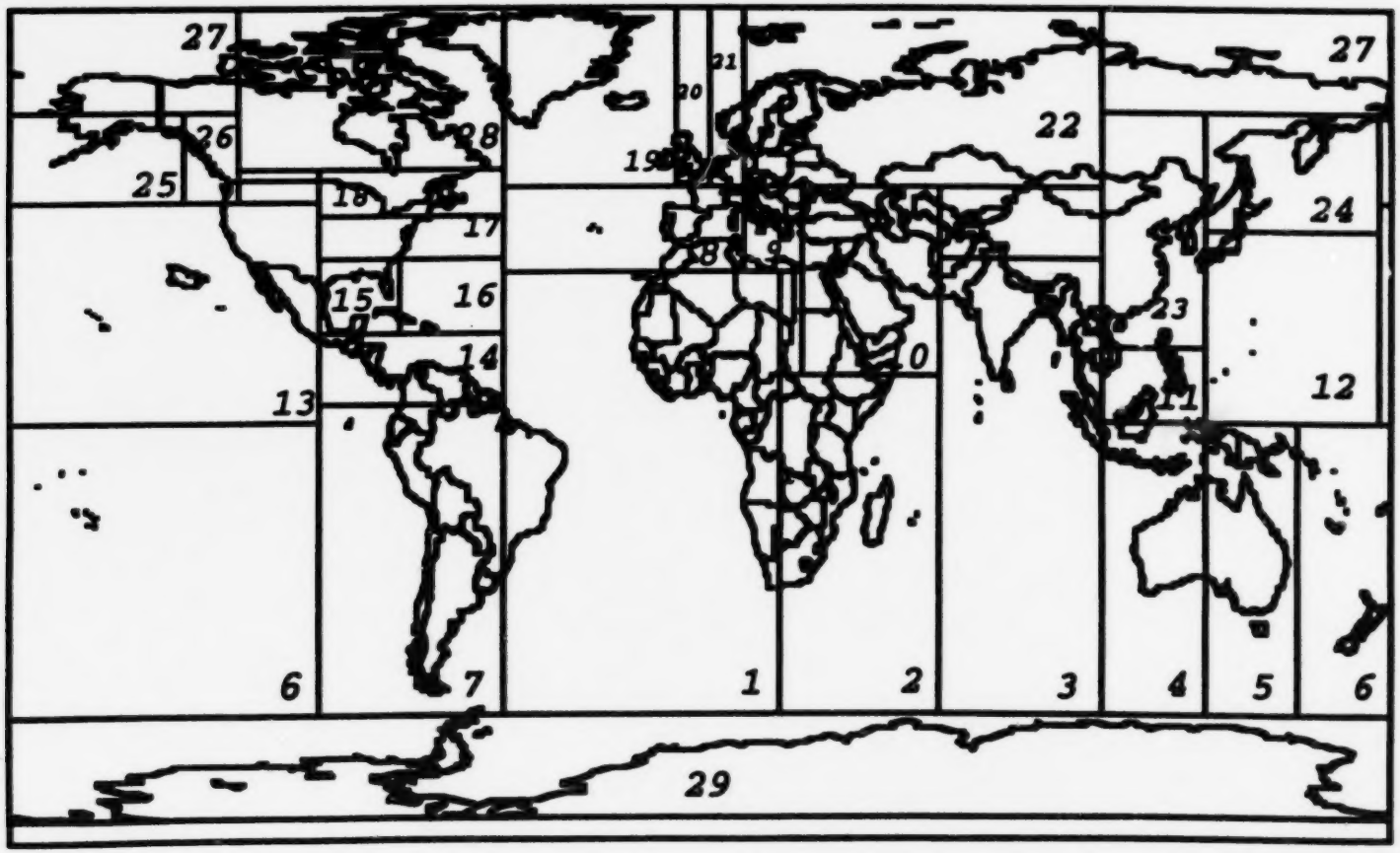
DNC DATABASE - Figure 1



/...

DNC CD-ROM Footprint

Figure 2



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The Vector Product Format: an overview

Paper submitted by the United States of America**

* E/CONF.90/1.

** Prepared by David M. Danko, Standards and Interoperability Division, National Imagery and Mapping Agency.

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INTRODUCTION

The National Imagery and Mapping Agency is chartered with providing products for the U.S. Military, Defense Agencies, and maritime customers. Increasingly these products are being produced in digital form. NIMA provides digital geospatial products primarily in three formats: Vector Product Format (VPF), Raster Product Format (RPF), and Text Product Format (TPF). Vector products account for the largest growth in the demand for digital data. NIMA produces a wide range of products which incorporate the VPF structure. The use of VPF for the distribution and direct application of geospatial information continues to expand.

BACKGROUND

Unlike many other government agencies which collect geographic information for internal use within their own organization, NIMA collects and furnishes geographic information, cartographic data, geodetic information, and navigation information to fulfill customer requirements. U.S. Federal, state, and local agencies collect and use geospatial information for use in forest, land, water, and energy resource management, as well as for public works, urban planning, and understanding population trends. Typically this information is provided to the public and the private sector as a low-cost by-product to promote growth, development, and recreation. The U.S. Department of Defense chartered NIMA with the responsibility to provide mapping, charting, geodetic, and geospatial information for use by the Army, Navy, Marines, Air Force, and Intelligence agencies, as well as for maritime navigation world wide. These products are used in a wide variety of activities such as strategic, regional, and tactical planning, mission planning and rehearsal, modeling for system development and performance testing, cockpit moving map display, on-board navigation, and many other applications.

As a customer oriented organization, NIMA maintains an active requirements collection component dedicated to working with customers to understand the type and format of data they require, as well as determining the geographic areas of the world for which they will need information. This component, as well as research and development groups within NIMA, works with weapons and other systems developers to insure that as new military systems and practices are developed, NIMA will provide the data they require. Data formats and digital products are developed using an iterative prototype design process to insure that NIMA products meet customer needs, and provide data in a readily usable form.

Geographic information standards such as the Spatial Data Transfer Standard (SDTS, U.S. Federal Information Processing Standards - FIPS 173) and NIMA's internal Mapping Charting Feature Data Exchange Standard (MC&GFDES) are examples of very robust standards designed purely for information exchange. MC&GFDES was developed for the exchange of data within a very large integrated production system. SDTS was developed to support the exchange of spatial data of any type between organizations using, in many cases, proprietary Geographic Information Systems. Data type/content can vary so broadly that it is impossible to write a general purpose translator designed to handle all SDTS possibilities. As a robust exchange standard SDTS is not designed to reduce the size of the data for Ease of distribution, nor provide indices for rapid access, nor carry redundant or pre-computed data for ease of access and use. It was not intended to be used for the distribution of products. FIPS 173 Paragraph 8 (Applicability) states: FIPS SDTS is not intended to facilitate product distribution of spatial data in a form designed for direct access by application software specific to a particular data structure, class of computer platform, or distribution media. Product standards such as RPF and VPF must support the use of application software that can access information regardless of variation in content. A product standard must efficiently store information to minimize the number of tapes or discs needed to distribute the data. It must incorporate indices providing users efficient access to information.

THE VPF STANDARD

The VPF standard defines the conceptual and physical data model on which all NIMA vector products are based. It uses a geo-relational model which is physically organized into five hierarchical levels: Database Level, Library Level, Coverage Level, Feature Level, and Primitive Level. The geospatial feature is the central concept of the VPF data model. Real world features are modeled by describing their location (where) and their properties (what). The Primitive Level carries the location information using four basic primitives: nodes, edges, faces, and text. These are implemented in five types of primitive tables: Node Tables, Edge Tables, Face Tables, Ring Tables (which link faces to edges), and Text Tables. These tables contain topologic relationships and coordinate data. Feature tables are used to describe the properties of a geospatial feature. Each record in a feature table identifies the feature, its attributes, and its primitive(s). Four types of feature/primitive relationships are possible: one-to-one, many-to-one, one-to-many, and many-to-many. Sets of features and primitives form coverages, which are grouped in libraries; a collection of libraries form a database.

VPF coverages group features by topologic relationships ranging from no explicit topology to full topologic relationships for all primitives. Varying degrees of integration are supported. When a product does not require relationships among data types, data can be stored in separate coverages; when full topology is required features may be combined into a single coverage. Complex features, groups of features collected together and handled as a single entity, may be modeled. Utilizing these concepts products may be designed as simple or as complex as necessary facilitating efficient storage and use.

Limitations caused by restrictions in computer memory or distribution media capacity require that

large geospatial databases be divided into manageable units, or tiles. VPF supports tiling using a concept of organizing primitives by geographic units and provides inter-tile topology to maintain geographic features in a logically continuous manner across tile boundaries. To the user, the data appears as one seamless unit.

Some other features of the VPF which enhance the utility of geographic information are:

Self Describing Format - each VPF level has header tables that describe the information contained at that level and a description of the level below. Each VPF table has a header describing the table. This allows software developers to design utility software which can adapt to any VPF database regardless of product design.

On-line Data Dictionary - The VPF data dictionary allows the definition of features and attributes to be carried with the product to avoid misinterpretation by users. The VPF utilizes "Value Description Tables" that specify and describe the feature attributes used in each coverage. Users can employ this capability when adding their own data to the database. They can describe feature and attributes which have been developed solely for their own purposes. These can be defined in the database and passed on for all to use. This allows each coverage to be used by a wide range of users without prior knowledge of a coding system - enhancing interoperability and insuring the data is interpreted correctly.

Data Quality - VPF provides the capability to carry data quality information at the Library, Coverage, and Feature Level. This information will help the user perform geographic analysis. It allows users to weigh a product's accuracy, currency, and completeness when performing analysis.

The VPF standard defines a general database structure and rules for how to model geospatial feature geometry, topology, and attribute information. It does not define what features, geometry, topology, and attributes are to be carried in a data set. Product Specifications are used to describe what is to be included in a data set using the rules defined by the VPF standard. They specify what type of geometry: x-y coordinates on a plane or latitude-longitude coordinates on an ellipsoid, whether these coordinates will be 2-dimensional or 3-dimensional; what level of topology; and what features and what attribution will be carried in a product. All within the limits defined by the VPF standard.

As a Military Standard, VPF documentation is available to the public through the Defense Printing Service Detachment Office. Previously known as MIL-STD 600006, the VPF military standard has been updated and the new version has been assigned MIL-STD 2407. The standard can be accessed

through the NIMA Homepage on the INTERNET (http://www.nima.mil). The standard can also be ordered by writing to:

Defense Printing Service Detachment Office:
Standardization Document Order Desk
Building 4D
700 Robbins Ave.
Philadelphia, PA 19111-5094
USA

To understand each NIMA product, a product specification must be used along with the VPF standard. These military specifications describe an implementation of the VPF standard.

VPF DATA AVAILABILITY

A wide variety of geospatial information is available in VPF. Development of new products continue as NIMA customer's requirements and applications expand. Many of these product specifications are available through the NIMA homepage on the INTERNET (http://www.nima.mil).

Digital Chart of the World/VMap Level 0

The Digital Chart of the World (DCW) is a comprehensive 1:1,000,000 scale equivalent resolution basemap of the world. The database is contained on four compact disc read only memory (CD-ROM). The database contains more than 1,500 megabytes of vector data and is organized in 10 thematic layers. The data includes major road and rail networks, major hydrologic drainage systems, major utility networks (cross-country pipelines and communication lines), all major airports, elevation contours (1000 foot(ft), with 500 ft and 250 ft supplemental contours), coastlines, international boundaries and populated places. The DCW also includes an index of geographic names to aid in locating areas of interest. The DCW is designed to support geographic information system (GIS) applications.

Edition 2 of the DCW will be released March 1997 as VMAP0 and is undergoing several design changes incorporating it into the Vector Map (VMap) series of products. International boundary information will be updated incorporating the latest changes as approved by the U.S. State Department. Vegetation information will be expanded to include all of North America. Global bathymetric information will be added in the form of depth contours. VMAP0, as with all NIMA vector products, uses the Feature Attribute Coding Catalog (FACC) which is Part 4 of the Digital Geographic Information Exchange Standard for feature and attribute definition. The DCW is available to the general public (as will VMAP0) through the U.S. Geological Survey, Earth Science Information Center (303-236-7477). The VMap0 is described in military specification MIL-D-89039.

World Vector Shoreline+

World Vector Shoreline (WVS+) is a product contained on a single CD-ROM which contains the world's shoreline at an equivalent resolution of 1:250,000. It also includes international boundaries including off-shore territorial boundaries and country names. Also included are representations of the world's shoreline at equivalent resolutions of 1:500,000, 1:1,000,000, 1:3,000,000, and 1:12,000,000. WVS will be available to the general public. Any vendor or publicly available software capable of reading VPF will be able to provide access to this database. The WVS+ is currently in production and will be available for public sale in December 1996.

Digital Nautical Chart

Digital Nautical Chart (DNC) products consist of VPF databases comprised of varying resolution libraries over a specified operational area. These libraries contain maritime significant geographic and navigation information typically found on standard nautical charts. Each library consists of 12 coverages: Cultural Landmarks, Earth Cover, Environment, Hydrography, Inland Waterways, Land Cover, Limits, Aids to Navigation, Obstructions, Port Facilities, Relief, and Data Quality. As an example a DNC may contain a General Library containing 1:1.2 million scale equivalent data; a Coastal Library containing 1:300,000 scale data; an Approach Library containing approximately 1:75,000 scale data; and a Harbor Library containing 1:20,000 scale equivalent information. When used by a navigator on-board ship, varying levels of detail are accessed by switching libraries as needed. Several DNCs have been completed and production is underway to cover the world's major ports by 1997. This will be produced by digitizing 4000 nautical charts. The DNC may become available to the general public pending a legal review by the International Hydrographic Organization. Its design is described in military specification MIL-D-89023.

Vector Map

Vector Map (VMap) is a suite of products which contain basic topographic geospatial data at a variety of levels of resolution. All VMap products contain identical thematic coverages: Boundary, Data Quality, Elevation, Hydrography, Industry, Physiography, Populated Places, Transportation, Utilities, and Vegetation.

VMap Level 0--VMap Level 0 is identical to the DCW described above.

VMap Level 1--VMap Level 1 will consist of approximately 234 CD-ROMs covering the world with 1:250,000 scale equivalent information. World coverage is expected by 2000. VMap is fully described elsewhere in this publication. VMap Level 1 CD-ROMs covering areas which are not bound by international agreements restricting release will be made available to the general public. VMap Level 1 design is described in MIL-V-89033.

VMap Level 2--VMap Level 2 consists of information with a resolution equal to 1:50,000 to 1:100,000 scale data. Individual Level 2 products cover small geographic areas determined by the

geographic operational requirements of NIMA's customers. Because of the sensitivity of this large scale information within many countries of the world, most Level 2 data will be restricted. The VMap Level 2 design is described in MIL-V-89032.

Urban VMap--As the name implies UVMap products cover urban areas. These products provide information at resolutions ranging from 1:5,000 to 1:50,000. Although it uses the same 10 thematic coverages as other VMap products, feature content and the level of attribution are much richer. Like Level 2 many UVMap products will not be releasable to the general public. The UVMap product design is described in MIL-U-89036.

VPF APPLICATIONS

Listed below are several software applications packages which make use of VPF products. The products mentioned are just a sampling to provide an understanding of what is available. It is not a recommendation; any product which uses VPF and is not mentioned, was left out unintentionally.

VPFView Software

VPFView software is designed to access any database implemented in VPF. It allows the display of chosen combinations of features or themes for a user selected geographic area of interest. The software supports the display of VPF databases directly from CD-ROM, hard drive, or diskette without loading or converting the data. Display scale can be changed by zooming in or out. Portions of a database can be copied from removable storage media and saved on a computer's hard disk in VPF. Simple plots can be generated in postscript format. Source code is available to provide developers methods for importing the data into their proprietary systems. A users manual is included. Both VPFView DOS (Order Number PB94-501715GEI) and VPFView UNIX (Order Number PB94-501723) versions are available through the U.S. National Technical Information Service (NTIS):

U.S. Department of Commerce
NTIS
5286 Port Royal Road
Springfield, VA 22161
703-487-4650, FAX 703-321-8547

MC&G Utility Software Environment

MC&G Utility Software Environment (MUSE) Version 1.0 was developed by the NIMA to provide a sample suite of software exploiting NIMA digital products. MUSE operates in the Windows,Macintosh, and SUN MOTIF/Openlook environments. Full source code is provided to allow users to understand and develop their own versions of access software. MUSE provides routines to access and process a wide variety of NIMA products such as: Arc Digitized Raster Graphics (ADRG), Compressed ADRG (CADRG), Controlled Image Base (CIB), Digital Terrain Elevation Data (DTED) and a wide variety of VPF products. MUSE supports raster importing,

vector importing, demonstration/briefing display tools, map fusion (overlaying raster data with vector information), standard NIMA datum transformations and coordinate conversions, line of sight computation and display, and perspective scene generation by fusing raster map data and elevation data. MUSE will extract data from VPF products; spatial extent is defined by entering geographic coordinates for the desired area; thematic selection is performed by allowing the users to define the coverages, libraries, and feature types to be accessed. VPF databases can be filtered by attribute by creating thematic expressions. MUSE is distributed by NIMA on CD-ROM along with full documentation and sample data sets.

MIGRATION TO DIGEST

As a U.S. Military Standard VPF is a controlled document, a stable design model, used for procurement and referenced by product specifications. The VPF geographic data model is based on the geographic model defined in the Digital Geographic Information Exchange Standard (DIGEST). VPF is equivalent to the implementation model defined in DIGEST Annex C, Vector Relational Format (VRF). DIGEST was developed by the Digital Geographic Information Working Group (DGIWG) a group of military map producers from 11 NATO nations. DIGEST, NATO Allied Geographic Publication 3 (AGeoP 3), has been ratified as NATO Standardization Agreement 7074 (STANAG 7074). In keeping with the DoD trend of moving away from the use of military standards, future producers and users implementing this vector relational model will drop the reference to the VPF Military Standard, and instead reference the internationally controlled DIGEST, STANAG 7074.

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SIXTH UNITED NATIONS REGIONAL
CARTOGRAPHIC CONFERENCE FOR
THE AMERICAS
New York, 2-6 June 1997
Item 5 (a) of the provisional agenda*

REVIEW OF THE LATEST TECHNOLOGY IN CARTOGRAPHIC DATA ACQUISITIONS, MANIPULATION, STORAGE AND PRESENTATION, WITH SPECIAL EMPHASIS ON POTENTIAL APPLICATIONS IN DEVELOPING COUNTRIES: AUTOMATED MAPPING PROJECTS: DEVELOPMENT AND APPLICATION OF DIGITAL CARTOGRAPHIC DATABASES, INCLUDING DIGITAL TERRAIN MODELLING

Access to geographic names data sets on the Internet: developments in the United States since 1994; the GEOnet Names Server

Paper submitted by the United States of America**

* E/CONF.90/1.

** Prepared by R. E. Flynn, United States Board on Geographic Names, National Imagery and Mapping Agency.

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At the seventeenth session of the United Nations Group of Experts on Geographical Names, the Convenor of the Working Group on Toponymic Data Files and Gazetteers observed that "... networks and the information highway (Internet) were rapidly changing the entire process of collection and exchange of [toponymic] information." The validity, indeed prescience, of the Convenor's remark is underscored by steps undertaken by the U.S. Board on Geographic Names (US BGN), the Canadian Permanent Committee on Geographical Names (CPCGN), and other normative bodies in their imaginative and beneficial application of communication tools made possible by the Internet. This report summarizes activity in this area by the Foreign Names Committee of the US BGN.

The foreign geographic names holdings of the US BGN first came on-line on the Internet in October 1994 at a World Wide Web (WWW) site known as the GEOnet Names Server (GNS). The GNS provides a query interface and a tabular display of results similar to the appearance of a page from the well-known series of BGN hard copy gazetteers. Initially, a user required an account and password to gain access to the GNS; this requirement was lifted in May 1996, and users may now access the GNS directly without prior registration with the US BGN. This service is provided to the public without restriction, without cost, and without warranty.

The data base served by the GNS contains records for approximately 3,300,000 geographic features around the world, and 4,700,000 geographic names (figures current as of March 1997). As in the hard copy gazetteers, variant name spellings are cross-referenced to standard names. The currency of the data corresponds to the currency of the associated hard copy BGN gazetteer. Geographic features in the United States and it possessions and Antarctica may be found in the U.S. Geological Survey's Geographic Names Information System (GNIS).

Though the GEOnet Names Server has not been actively publicized, its use in the Internet community has steadily grown in the twenty months since it has been on-line. The peak month to date was February 1997 with over 53,000 data base queries recorded. Use of the Server appears to be evenly split among government (.gov), academic (.edu), and commercial (.com) users. While most queries to the Server originate in the United States, the level of international use is growing.

The principal difficulties associated with the Server are transmission of diacritical marks, and data currency. The Internet currently supports transmission of text data in a variety of text encoding standards. Correct display of the text data depends on matching the text encoding standard employed by the server with the same standard at the client. The client must then employ a soft copy font that displays the encoded text accurately. The GEOnet Names Server at present can supply names data that is compliant with the ISO 8859 Latin 1 standard, which renders text in many Western European languages. At this time, diacritics and special letters not covered by this standard cannot be accurately displayed using data from the GNS. The conversion of our data base to the ISO 10646 standard, and the availability of ISO 10646-compliant fonts, will overcome this problem. This conversion is anticipated over the next two years.

The second problem - data currency - can only be overcome by the availability of authoritative digital names data from national normative bodies. This data is currently in short supply, a problem compounded by the lack of an agreed-upon toponymic data exchange format. Resolution Seventeen of the Fifth United Nations Conference on the Standardization of Geographical Names calls upon the United Nations Group of Experts on Geographical Names (UNGEGN) to "... investigate the possibility of preparing guidelines for direct communication with, and exchange of toponymic information between, various computer systems." The Eighteenth Session of UNGEGN in Geneva, 12-23 August 1996, featured the formation of a special Working Group, consisting of Mr. Roger Marsden of Great Britain, Mr. Peeter Pèll of Estonia, and the author, to investigate and report on a strategy for a workable solution to international digital toponymic data exchange.

The GEOnet Names Server is located at http://www.nima.mil/. Select the "Geospatial Information" option to find the link to the Server. Alternatively, access the Server at http://164.214.2.59/gns/html/index.html. Links from the Server direct the user to other sites of interest to geographic researchers, including the GNIS noted above, and the national data base of Canadian geographic names maintained by CPCGN.

The author welcomes suggestions regarding improvements in GNS service, and is available for more detailed consultation. Report of the United Nations Group of Experts on Geographic Names on the work of its Seventeenth Session, GEGN/17, 2 August 1994, p. 19. Report of the United Nations Group of Experts on Geographical Names on the Work of its Seventeenth Session, GEGN/17, 2 August 1994, p. 19.

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REVIEW OF THE LATEST TECHNOLOGY IN CARTOGRAPHIC DATA ACQUISITION, MANIPULATION, STORAGE AND PRESENTATION, WITH SPECIAL EMPHASIS ON POTENTIAL APPLICATIONS IN DEVELOPING COUNTRIES: AERONAUTICAL CHARTING

GPS/GIS integrated systems to benefit all phases of aircraft navigation

Paper submitted by United States of America**

Summary

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** Prepared by Ronald M. Bolton, National Ocean Service, National Oceanic and Atmospheric Administration.

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INTRODUCTION

The U.S. Department of Defense Global Positioning System (GPS) program was born in 1973 from the initial efforts by the U.S. Navy to develop an all weather global radionavigation system. GPS is a multibillion dollar satellite positioning and navigation network. Its use has been extended to civilian land, marine and air navigation, providing incredibly accurate, worldwide navigation and positioning capabilities. GPS can be accessed by U.S. and international users and requires no user fees.

GLOBAL POSITIONING SYSTEM DESCRIPTION

GPS consists of 21 satellites and 3 operational spares. The satellites orbit at 10,900 miles above the earth and complete each orbit in approximately 12 hours. The GPS satellites constantly transmit their position in space and reference time; the time is accurate to one second in 30 years. With this accurate time and position data, GPS receiver systems compute very accurate positions at anytime without interference by weather conditions.

GPS receiver systems must obtain signals from a minimum of three satellites to resolve the latitude and longitude of a point, and four satellites to determine the latitude, longitude and elevation of a position. The GPS receiver generally can lock on to the satellite signals and provide two dimensional fixes in 2 to 3 minutes and three dimensional fixes in 3 to 4 minutes. Once the receiver has resolved its initial position, it can provide position and time updates in a matter of seconds.

GPS NAVIGATION CAPABILITIES AND IMPLEMENTATION STATUS

GPS, even without augmentation, can still be used for accurate navigation for most purposes. The GPS basic signal provides very accurate navigation positioning. Compared with other navigation systems, GPS, in its most elementary form, is one or two magnitudes more accurate than conventional systems as depicted in Table 1.

Table 1: Navigation System Comparison*

System	Position Accuracy (m)	Velocity Accuracy (m/sec)	Range of Operation	Comments
GPS	15 (SEP) 3-D	0.1 (RMS per axis	Worldwide	Operational worldwide with 24-hour all-weather coverage. Specified position accuracy available to authorized users.
Loran-C (Note 1)	180 (CEP)	No velocity data	U.S. Coast, Continental U.S., selected overseas areas	Operational with localized coverage. Limited by skywave interference.
Omega (Note 1)	2,200 (CEP)	No velocity data	Worldwide	Operational worldwide with 24-hour all-weather coverage. Degraded performance in polar areas.
Std INS (Note 2)	1,500 max after 1st hour (CEP)	0.8 after 2 hrs (RMS per axis)	Worldwide	Operational worldwide with 24-hour all-weather coverage. Degraded performance in polar areas
TACAN (Note 1)	400 (CEP)	No velocity data	Line of sight (present air routes)	Position accuracy is degraded mainly because of azimuth uncertainty which is typically on the order of +/-1.0 degree.
Transit (Note 1)	200 (CEP)	No velocity data	Worldwide	The interval between position fixes is about 90 minutes. For use in slow moving vehicles. Better position fix accuracy is available with dual frequency measurements.

NOTES: 1. Federal Radio Navigation Plan, March 1982
2. ENAC-77-IV, Characteristic for a Moderate Accuracy Inertial Navigation System, August 1979

Used with assistance from geostationary satellites, local area differ-ential systems, and wide area augmentation systems, GPS can provide aircraft sufficient integrity, accuracy and availability to support enroute, landing and departure operations.

DoD declared GPS operational in the U.S. on December 8, 1993. FAA subsequently has granted approval for U.S. civil operators to use GPS equipment as a primary means of navigation in oceanic airspace and certain remote areas. GPS equipment may be used as a supplemental means of Instrument Flight Rules (IFR) navigation for domestic enroute, terminal operations and certain instrument approach procedures (IAPs). FAA has authorized the use of GPS in a manner that is consistent with current navigation requirements and approved air carrier operation specifications.

FAA has approved the use of GPS for IFR aircraft navigation in the U.S. National Airspace System (NAS) with certain stipulations:

- Oceanic - The GPS installation meets the requirements of TSO C129 and replaces one of the approved means of long range navigation, such as dual Inertial Navigation Systems (INS) or dual Omega systems. A single GPS installation with a type of GPS equipment which provides

receiver autonomous integrity monitoring (RAIM)* may be used for short oceanic routes which are approved for utilization with only one means of long-range navigation.

- Enroute and terminal area - GPS domestic enroute and terminal IFR operations can be conducted as soon as proper avionics equipment is installed in an aircraft and general requirements for flight are met. The avionics necessary to receive all the ground-based facilities appropriate for the route to the destination airport and alternate airport must be installed and operational. Ground-based facilities necessary for these routes also must be operational.

- Instrument approaches - Published GPS Approach Overlay IAPs and Standalone IAPs are authorization for pilots to use with GPS avionics under IFR; however, these approaches must be included in the receiver's database or the approach is not authorized.

Aircraft navigators worldwide are demanding full GPS implementation. Expected benefits are reduced travel time, more efficient travel paths, and reduced delays (especially in poor weather conditions)--all of which are made possible by flight procedures supported by more accurate GPS navigation systems, airborne and ground-based databases, and reliable surveillance equipment augmented by GPS.

*The GPS receiver verifies the integrity of the signals received from the GPS constellation through receiver autonomous integrity monitoring (RAIM) by ensuring that a satellite is not providing corrupted information. At least one satellite, in addition to the four required for navigation, must be in view of the aircraft to have RAIM function.

LONG RANGE PLANS FOR GPS

The *Federal Radionavigation Plan (FRP) 1994*, published by the U.S. Department of Defense and Department of Transportation, left no question as to the long range plans for GPS. The FRP stated that, "GPS has broad potential for satisfying current civil user needs or for responding to new requirements that present systems do not satisfy. It could ultimately become the primary worldwide system for military and civil navigation and position location." The FRP cited evidence that there was increased interest and use of GPS for air navigation since the 1994 approval of unaugmented GPS as a primary system for oceanic and remote airspace navigation. The 1994 FRP designated the GPS Wide Area Augmentation System (WAAS)as a candidate for certification as a primary aircraft navigation system. Table 2, published in the 1994 FRP, clearly shows the aviation community has embraced GPS as the navigation system of the future.

Table 2: Estimated Current Radionavigation System User Population

Systems Users	0 50 100 150 200
ILS/Air	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
*Loran/Air	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
Loran/Land	XXXXXXXXX
Loran/Maritime	XXXXXXXXXXXXXXXXXXXX

GPS AND AUGMENTED GPS ACCURACIES

The positional accuracies listed below of GPS and augmented GPS explain government and aviation interest in these systems:

Kinematic Accuracies

- GPS Precise Positioning Service (PPS)
  - 15 meters (95%)
- GPS Standard Positioning Service (SPS)
  - 100 meters (95%)
- Wide Area Augmentation System (WAAS)
  - maximum test errors determined by Stanford University and Stanford telecommunications: vertical error was 9 meters and horizontal error was 6 meters. Over the whole continent, the average was under 2 meters.
- Local Area Augmentation System (LAAS)
  - instrument approach test errors: Ohio University using differential GPS achieved error rates under 2 meters, Stanford University making approaches using carrier phase corrections and integrity beacons had error in the .1 meter range.

A quick review of these accuracies achieved in the kinematic mode reveals that GPS and augmented GPS can meet all requirements for enroute, terminal, approaches (including categories I, II and III), and departure operations.

INTEGRATION OF GPS AND DATABASES TO SUPPORT AIRCRAFT NAVIGATION AND AIR TRAFFIC MANAGEMENT SYSTEMS

Aircraft of the future will include significant enhancements in communication, navigation and surveillance capabilities. The majority of communications between aircraft and air traffic management (ATM) systems will be conducted by redundant, high speed data links. GPS navigation signals, augmented by WAAS enroute and LAAS during the approach and landing phases, will provide highly accurate position and universal time standards. Automated Dependent Surveillance - Broadcast (ADS-B) equipment on board aircraft will provide position and other important data to the cockpit displays, nearby aircraft, as well as controllers in the ATM system.

These systems, as described above, will interface with the pilot through controls and displays that may be similar to the latest generation "glass" cockpits available now; however, the next generation of cockpit equipment will be more capable than current systems. The pilot will be supported by databases, processors, and networks that will provide storage, manipulation, display, and external/internal communications involving massive volumes of data; these pilot support systems will be capable of processing all essential or critical flight information. Future advanced automated functions will include data for:

- Area navigation (lateral and vertical)
- Auto loading of flight plans, flight trajectories, winds, and temperatures
- Data link communications - including air-to-air, ground-to-air, and air-to-ground
- Separation assurance from terrain, obstacles, special use airspace and other aircraft
- Weather information - graphic and digital
- Flight management data - waypoints, altitude and informative text (enroute, approach and departure)
- Airport data - gates, surface movement, runways, taxiways, lighting, etc.
- Collision avoidance data
- Aircraft operation information and warnings
- Display data for moving maps/charts - navaids, controlled airspace boundaries, route data, magnetic variation, obstacles, VFR chart depictions, flight path position, etc.

In the near term, these automated functions will immediately require supporting databases such as those key data sets listed below:

- Controlled Flight into Terrain (CFIT) Protection - Many of these functions will require current and projected future positional data supplied by GPS. GPS data will be critical in Obstacle and Ground Collision Avoidance Systems. Predictive systems will use GPS and terrain/obstacle data to provide advisory or automatic thrust/climb management as well as graphic terrain surface displays.
- Airport Surface Operations - GPS data combined with airport data (i.e., runways, taxiways, buildings, etc.) will assist in avoiding accidents, especially in low visibility conditions.
- Flight Management Systems (FMS) - Flight Management Systems use GPS, inertial, and Loran C navigation systems coupled to databases containing fix, waypoint, and altitude data for enroute, terminal, approach, landing, and departure phases of flight. These FMS databases will need to be linked/integrated with other databases -- especially the CFIT Avoidance System.
- Controlled Airspace (CA) and Special Use Airspace (SUA) - CA and SUA databases will be required for efficient aircraft and ATM operations. The SUA data would allow planes to transit these areas at approved altitudes when they are inactive.

AVIONIC COMPANIES USING GPS AND DATABASES FOR CHART AND MAP DISPLAYS

The concept of combining GPS data with integrated databases to display fix and moving maps/charts to enhance situational awareness and improve aircraft navigation has been embraced by avionics manufacturing companies† and chart producers. Many operational systems are in operational use now that offer some or all of the following features:

- Position and altitude display/control
- Map/chart displays
- Weather data and displays
- Enroute, approach, departure, and visual chart displays
- Video displays
- Waypoint sequencing
- Minimum safe altitude data
- Political boundary data
- Coastline data
- CFIT displays and warnings
- Airport graphics and/or data

These are the key databases being linked with GPS to provide navigation improvements and enhanced situational awareness for aircraft and better information for ATM.

GPS, CHART, DATABASE, FMS, ATM SYSTEMS INTEGRATION AND QUALITY CONTROL

FAA and the International Civil Aviation Organization (ICAO) are working with RTCA, Inc. and SAE International Aerospace, the key standards groups for the aviation industry, to assure proper standards and procedures are developed and implemented to allow safe aircraft operations in the NAS and worldwide. The ATM system, the aircraft navigation system, and the pilot must be supplied the same consistent, accurate, operational information in a form that facilitates navigation and enhances situational awareness. Without technical standards and proper certification procedures, the integrated GPS/database systems might not contribute to safe and efficient flight in an optimum manner. In any case, the aviation community must be supplied charts, FMS databases, and ATM data and displays that are certified as accurate and consistent; otherwise, the advantages of GPS and integrated database systems will be negated and even might become a hazard to aircraft navigation.

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†A few of the avionics, navigation systems, and chart producers active in this area include: Jeppesen, Collins, Trimble, Bendix/King, II Morrow, Smith Industries, Honeywell, Megellen, and Allied Signal, Inc.

IMPACT ON AERONAUTICAL CHARTS AND RELATED PRODUCTS

The use of GPS in the U.S. NAS has created significant impacts on aeronautical charts and related products. Enroute charts have been modified to include geographic positions (GPS information for use in flight computers), Off-Route Obstruction Clearance Altitudes (OROCAs) have been added, and the IACC has changed the U.S. High and Low Enroute charts from two colors to four colors to give pilots and navigators enhanced situational awareness as they increasingly choose to fly off-route in a more dynamic mode.

In the instrument approach chart area, the impact has been very dramatic. Over 3,347 charts have been published that allow the approaches to be made with traditional navaids "or" GPS. Seven hundred and ninety seven GPS (standalone) approaches have been published; thus, over one half of all U.S. published approach charts are associated with GPS.

Future impacts for chart producers will be even more extensive and dramatic:

- Instrument approach charts will be reformatted and be produced in both digital and paper analog forms.
- Enroute charts will be reformatted and a companion product for off route enroute area navigation will be produced as a new series of charts. (The IACC has started deliberations on the specifications for this new enroute series.) Enroute charts will be published in digital and paper analog forms.
- Publications that supplement and augment IFR and VFR products will be issued in analog and digital forms.
- Databases will be created and issued for use in "value added" cockpit navigation systems.

BENEFITS OF UTILIZING GPS/GIS INTEGRATED SYSTEMS

Technological change in the aviation industry in the last 5 years has been rapid and will continue to accelerate dramatically well into the next century. The enhanced computers, improved data storage devices, advanced digital and graphic display systems, and GPS have enabled the industry to develop improved cockpit avionics, more accurate navigation capability, real time access to flight information, better communication networks, and improved air traffic management (ATM).

Near term benefits derived from GPS/GIS integrated systems include fewer traffic restrictions, better navigation capabilities, increased NAS user flexibility, and increased NAS capacity. Longer term benefits will include an improved ATM system with enhanced automation and mature supporting infrastructure that will allow aviators to fly optimized routing.

A unique development that will impact and benefit the airborne and ground based segments of the NAS is the Automated Dependent Surveillance - Broadcast (ADS-B). The ADS-B will allow aircraft equipped with traffic displays to see other ADS-B equipped aircraft and allow ATM to know the GPS

derived position of the equipped aircraft. Thus, this improved surveillance technology will provide more accurate position reports for use by controllers, pilots, and automated systems in the function of aircraft separation assurance.

GPS will allow accurate aircraft navigation in all types of weather; thus, many current weather-related flight delays will be avoided. Augmented GPS will also bring an end to the necessity for ground based navigation and landing systems for aircraft. Integrated GPS/GIS systems will provide substantial cost savings to the aviation industry.

The greatest benefit of these systems will be increased safety for the aviation community through better situational awareness provided to both pilots and the ATM system managers by GPS/GIS integrated systems.

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REVIEW OF THE LATEST TECHNOLOGY IN CARTOGRAPHIC DATA ACQUISITION, MANIPULATION, STORAGE AND PRESENTATION, WITH SPECIAL EMPHASIS ON POTENTIAL APPLICATIONS IN DEVELOPING COUNTRIES: AUTOMATED MAPPING PROJECTS: DEVELOPMENT AND APPLICATION OF DIGITAL CARTOGRAPHIC DATABASES, INCLUDING DIGITAL TERRAIN MODELLING

The Inter-American Geospatial Data Network: developing a western hemisphere geospatial data clearinghouse

Paper submitted by the United States of America**

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INTRODUCTION

Establishing the Inter-American Geospatial Data Network (IGDN) is a project of the U.S. Agency for International Development (USAID) and the U.S. Geological Survey (USGS), in cooperation with organizations throughout the Americas. The objective is to promote access to information that describes the existence and availability of geospatial data sets by means of the Internet. IGDN participants are producing digital geographic information and applying it to problems of sustainable development. The project is being carried out in the context of USAID's efforts to promote environmentally sound economic development. In its efforts to strengthen the Western Hemisphere's information infrastructure, it is consistent with the goals of the Plan of Action that emerged from the 1994 Summit of the Americas.

Geographic information system (GIS) technology is being used increasingly by professionals in a wide variety of disciplines to plan and implement scientific research, commercial investments, environmental policy, civil infrastructure management, and conservation activities. Consequently, there is a growing demand for digital geographic data sets, especially in base categories such as topography, hydrography, roads, populated places, and administrative boundaries. The IGDN is envisioned as an online clearinghouse to facilitate the discovery of existing data sets and to avert duplication of effort in creating new data sets. Two tasks central to the IGDN are the creation of standardized, descriptive text files, or "metadata," and the use of search engine technology to support remote query and retrieval.

CLEARINGHOUSE TECHNOLOGY

The IGDN is based on the same technology used by the Federal Geographic Data Committee (FGDC) to establish the U. S. National Geospatial Data Clearinghouse. In 1994, President Clinton signed U.S. Executive Order 12906, "Coordinating Geographic Data Acquisition and Access: The National Spatial Data Infrastructure" (White House, 1994). The order directs U.S. agencies to document geospatial data and make them available to the public. It calls upon the FGDC to develop the standards, organizational guidelines, and software solutions that assist organizations as they work to implement the Executive Order. A major activity of the FGDC is the development of a national clearinghouse as a distributed, electronically connected network of geospatial data producers, managers, and users. A clearinghouse allows its users to determine what geospatial data exist, evaluate the usefulness of the data, and obtain data.

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The USGS is using FGDC standards and guidelines to establish the IGDN as a geospatial data clearinghouse for the Western Hemisphere. The IGDN provides a consistent data discovery mechanism that will help minimize geospatial data duplication, promote data availability, and coordinate data collection and research activities.

An IGDN node houses and serves an organization's metadata and optionally its geospatial data. Initially, five organizations have been invited to participate from government, academic, nongovernment organizations, and the commercial sector. These initial nodes include CODEPLAN, the planning agency for the Federal District of Brasilia, Brazil; Conservation International, an environmental nongovernment organization in Washington, D.C.; GEOSCAPE International, a commercial firm in Boca Raton, Florida; IBGE, the Brazilian mapping and statistical agency in Rio de Janeiro, Brazil; and the University of Kansas GIS and Environmental Modeling (GEM) Laboratory in Lawrence, Kansas. The IGDN membership is being further expanded to include potential participation in the geospatial data community through USAID Missions, current IGDN members, the Pan American Institute of Geography and History (PAIGH), and other professional organizations.

METADATA

Metadata are at the heart of the IGDN. Metadata consist of standardized text files describing the content, quality, constraints, availability, format, means of access, and cost of existing geospatial data sets. Major uses of metadata include the ability to represent an organization's data holdings to clearinghouses and provide descriptive information necessary to process and interpret geospatial data sets.

Geospatial data can be difficult or impossible to use if unaccompanied by metadata. Metadata help users determine the suitability of geospatial data for their specific purpose. Data origin, accuracy, and attributes are fundamental elements in determining if the data are appropriate for a users analytical or cartographic needs. Data constraints, availability, format, means of access, and cost are elements used in evaluating whether data can be successfully integrated with an existing or planned GIS.

Metadata preparation and maintenance present a major challenge to organizations developing an IGDN node. Organizations need to develop a plan for documenting both new and existing geospatial data. An inventory of existing geospatial data is a first step to identify an organization's geospatial data holdings, as well as their location, condition, and content. The inventory will help define which data to document and include in the IGDN. Strategies and priorities for documenting the data need to be established on the basis of the data's greatest potential value to users. Criteria that may be used are the number and identity of interested users, unique nature of the data, age of the data, size of the data set, and cost of documenting the data. Trained personnel are essential to maintain current, high-quality metadata.

The rising popularity of the Internet has significantly increased access to georeferenced data. Because overwhelming amounts of information are available to the public, methods have been developed for geospatial data search and retrieval. A metadata content standard has been developed to provide the structure required for an effective geospatial data search on the Internet. The IGDN adheres to the metadata standard established by the FGDC, described in the "Content Standards for Digital Geospatial Metadata Workbook" Version 1.0 (FGDC, 1995). The standard defines a common set of approximately 300 terms and definitions to help an organization document its geospatial data. It does not, however, tell a producer how a computer system should prepare the information, transfer metadata and geospatial data, or present information to the user. The FGDC metadata content standard is the basis for a proposed international standard currently being reviewed by the International Organization for Standardization (ISO).

SEARCH AND RETRIEVAL

There are two levels of participation in the IGDN. Table 1 explains each level and its characteristics. Level 1 participants operate established, fully functioning IGDN nodes. Level 2 participants are organizations that have stated interest in pursuing node development with the IGDN but have not yet completed the preparation of metadata, installation of the search engine software, or development of the Internet interface.

The IGDN Clearinghouse uses a client/server model of computing to connect the numerous data providers and users on the Internet. The IGDN client consists of an Internet browser and a geospatial search form. The client sends the user's query to the server and receives the results. The server is an IGDN node consisting of four components: metadata describing geospatial data, hardware for storing indexed metadata, a dedicated Internet connection, and search and retrieval software. The server performs the query on the metadata and sends the query results to the client.

A search of the data is performed on the available IGDN nodes using the Internet and software that is compliant with the Z39.50 protocol. The Z39.50 protocol defines the way that two computers interact with each other. This open standard ensures interoperability of multiple machines and platforms. It has been approved by both the National Information Standards Organization (NISO) in 1995 and the ISO in 1991.

The searcher does not have to be familiar with details of the Z39.50 protocol to make an IGDN query. The searcher uses a browser to fill in the IGDN search form by specifying the IGDN nodes to be queried, a geographic area of interest, and thematic keywords. After the form is submitted, the client converts the query into a Z39.50 standardized format and sends it to the selected IGDN nodes over the Internet.

Each selected IGDN node receives the same query for processing. The search and retrieval software simultaneously processes the queries against the FGDC metadata on each node, significantly reducing the time required to return results. Nodes with matching metadata return brief descriptions of the data displayed on the user's browser.

Each metadata description contains associated hyperlinks to the full metadata files. The hyperlink allows the user to view the metadata in the browser. A user can then evaluate information in the metadata to determine if the data meet his or her specific needs.

The Z39.50 search and retrieval software allows the IGDN to be a decentralized system of data producers. The software is multi-threaded, allowing many servers to be searched at the same time. It also permits multiple users to conduct queries with each of the IGDN nodes simultaneously. The Z39.50 software allows the IGDN to be a distributed system of geospatial data nodes that document their data in the same vocabulary and support the same protocol.

IGDN STATUS

The IGDN project was established in October 1995. Project staff have developed a prototype web site that includes a fully functional search engine connected to IGDN nodes, provided participating organizations with technical assistance to establish their nodes, and developed outreach programs to increase the number of future participants. The IGDN can be accessed on the Internet at the Uniform Resource Locater (URL) *http://edcintl.cr.usgs.gov/igdn/igdn.html*.

Approximately 10 organizations have expressed interest in IGDN participation at level 1 or 2. Level 1 participants will continue to develop and maintain their IGDN nodes. Level 2 participants will receive technical assistance from the USGS to develop IGDN implementation strategies. Future efforts will be made to expand the number of Western Hemisphere geospatial data organizations participating in the project.

A workshop hosted by USAID, the USGS, and PAIGH will be held in July 1997. The workshop will train new IGDN participants in metadata preparation and standards, network searching software, data transmission and delivery, and web development. Scientists from participating organizations will learn to implement the IGDN technology as well as train new IGDN participants within their respective countries.

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Table 1. Levels of IGDN Participation

LEVEL & NAME	DESCRIPTION	REQUIREMENTS / IMPLEMENTATION
Level 1 IGDN Nodes	Full Federal Geographic Data Committee (FGDC) Clearinghouse implementation	• Western Hemisphere geospatial data • Metadata in FGDC format • Dedicated Internet connection • Search & retrieval software on UNIX or Windows NT • Organization's node is connected to the IGDN search engine's node registry • Organization listed as IGDN Node Page
Level 2 Future IGDN Nodes	Organizations interested in future clearinghouse node implementation	• Organization is a holder/distributor of geospatial data and has a WWW site • Contact has been established with IGDN staff to discuss project objectives • Organization concurs with IGDN concept and will develop plans for future integration • Organization's name, logo, and WWW site listed on Future IGDN Node Page

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REVIEW OF THE LATEST TECHNOLOGY IN CARTOGRAPHIC DATA ACQUISITION, MANIPULATION, STORAGE AND PRESENTATION, WITH SPECIAL EMPHASIS ON POTENTIAL APPLICATIONS IN DEVELOPING COUNTRIES: SURVEYING AND MAPPING, GEODESY, MAP UPDATING AND GENERALIZATION

Global vertical datum to survey accurate orthometric heights and depths

Paper submitted by the United States of America**

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** Prepared by Muneendra Kumar, National Imagery and Mapping Agency.

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INTRODUCTION

In the complex mapping, charting, and geodetic world, as it exists presently, there are hundreds of vertical datums in use. Some datums are properly defined, while in some cases there is hardly any validity in the definition. For many others, information is not available that can be used to determine an accurate height in the local system.

In the above environment, the definitions of the nautical chart datums and the depiction of all other related information useful for safe navigation to avoid underwater and/or overhead hazards vary from one chart to another, coast to coast, between charting agencies, and also between countries. Furthermore, in the hydrographic usages, statements like, "Owing to the many varied tidal characteristics, a precise scientific definition for chart datum, which could be used universally, has not been agreed upon" (IHO, 1993), can still be found. This situation arises due to our age old practice of measuring various time-dependent mean ocean surfaces, such as Mean High Tide (MHT), Mean High Water (MHW), Mean Lower Low Water (MLLW), Mean Sea Level (MSL), Mean Higher High Water (MHHW), Mean Low Water (MLW), Low Water (LW), High Water (HW), etc.

Then, due to our age old practices and usage, we still have not initiated any serious efforts to look for alternatives which are offered by 3-dimensional satellite survey techniques and our new capability in determination of geoid with high absolute accuracy. We still continue to use MSL and various tidal surfaces in relating them to land and nautical chart datums in depicting elevations or ocean depths.

The old approach has varied from one country to another and is dependent on the adopted MSL definition and tide models, surveying techniques, and durations for computing "mean" tidal surfaces, and instrumentation. As the sea level changes can be excessive and are also time-dependent, the knowledge of accurate tide modeling, which is always complex, becomes very critical. Thus, in this complex and difficult to measure time-dependent scenario, it is quite obvious why it would be difficult for all the countries to agree to a common datum for nautical charts and ocean depths.

However, we now have the capability to compute a geoid of very high accuracy over ocean areas and thus define an accurate vertical datum, which would be the same both for land and nautical charts all over the globe. This global datum will not use time-dependent tidal surfaces. Also, the availability of the Global Positioning System (GPS) makes it easy to establish this vertical datum, to survey

time-invariant land elevations and ocean depths in the field, to extend the control, and to depict them on charts.

Then, reversing the survey mode, these charted depths and can be realized in real-time during navigation to check depth clearances to avoid ship grounding. Similarly, elevation or height clearances can be determined for an isolated point or station on land.

This paper presents in detail the problems with the old zero surface(s), the realization of an accurate geoid, a new concept to define a global vertical datum completely time-independent, and the method to establish the same through GPS surveys. It also describes how to realize the seafloor depths during navigation. The approach thus eliminates the necessity for the time-dependent sea level and other tidal data as the primary source to establish and use depths and elevations.

PROBLEMS WITH CURRENT TIDAL LEVELS

Figure 1 shows an illustrative depiction to define various tidal and sea levels and charted data as these surfaces are used by some countries (NOAA, 1990), if not by all. Here, there are some inherent and practical problems when any such surface is selected to define a land and/or chart datum.

A. For Land Areas -

In case of vertical datums, at least, every country has used the same surface as zero reference, viz., MSL. However, the realized surface in such cases may NOT be the same and the selected zero may have many limitations.

(1) MSL is NOT an equipotential surface. It has slope with respect to the geoid.

(2) Practically, all Tidal Observation Stations (TOSs) are located inside the bays and not on the open ocean side along the coast.

(3) Some TOSs still have old and obsolete instruments.

(4) An accurate MSL requires observations taken regularly and un-interrupted over a cycle of 18.67 years.

It is interesting to note here, that this condition may NOT have been met in many of the selections. In one case, only one observation of the sea surface was used as MSL.

(5) As TOSs are situated along the coast in shallow waters, the selected MSLs do not represent the true mean sea level.

(6) In many "older" datums, the MSLs at all the TOSs used to define and adjust the level net were constrained to zero and this produced "distorted" networks.

Now, in recent times, an easier way was selected by using ONLY one TOS to avoid "distorted" level networks. In such a case, it is not clear how a large extended network over thousands of kilometer can be kept accurate and all elevations can be assumed to be within "permissible" errors far away from the "fixed" TOS. Of course, use of only one constraint in any adjustment is the most easy solution.

(7) In "land-locked" countries, the MSL has been borrowed from the neighboring country or countries.

A very interesting case is of Paraguay. Here, on the west side, the MSL may have been borrowed either from Chile or Peru and then through Bolivia. The level lines used run over the Andes and they may also have been "differently" processed. On the east side, the two MSLs may have been used, one from Brazil and other from Argentina. A closer study has revealed many problems.

B. For Ocean Areas -

The latest trend here is the use of the Lowest Astronomical Tide (LAT) as the vertical datum for nautical charts. In other cases, there are some interesting conflicts and deviations between various definitions in Figure 1. Mariners using the data based on these definitions would be facing hard times to understand and interpret them correctly, especially when hard pressed for time and faced with little margin of error. A few typical examples of such cases are:

(1) Use of MLLW as chart datum (CD) to depict charted depths versus use of chart LW (drying) line to depict drying heights.

(2) Use of Charted HW (coastal) line as land datum to depict charted elevations. Here, MSL is shown separately, even though all the land vertical datums worldwide are defined with respect to MSL.

(3) Both MHW and MHHW are shown differently from the charted HW (coastal) line.

(4) While charted depths are defined with respect to MLLW, the charted vertical clearances are defined with respect to MHW, and not to MHHW. This definition may leave MHHW practically with no application, at least in Figure 1.

(5) It is not clear how anyone can be sure that once established LAT zero surface would remain as the "lowest" surface for all future times. Further, it also would NOT be representing the same zero in different parts of the world.

In Figure 1, the "height of tide" is defined with respect to MLLW (CD), while Tide and Current Glossary (NOAA, 1989) does not define this important item. Further, this glossary includes Half-Tide Level, also called Mean Tide Level, to define a tidal datum which is midway between MHW and MLW; but the same is not included in Figure 1.

Table 1 (NOAA, 1990) shows a typical example of a tide table where tidal levels are related to "Datum of Soundings". Here, a user will then have to solve or interpret a newer set of terms like MHWS, MHWN, MLHW, and MHLW. All this will make the use of available information more complex and thus difficult to interpret correctly. The note in Table 1 indicates that the order of the included tidal levels, as referred to all the sounding datums, may be different in other national tables. If this statement is taken to be correct, the involved definitions of all these terms may also be different (IHO, 1993).

Another important aspect in all of the above complexity of terminology and definitions is that all this information may also be time-dependent and have vertical bias between different level surfaces used by different countries.

ALTERNATE SOLUTION

On land, the orthometric heights or elevations are defined theoretically with respect to the geoid. However, in the past, due to our limitations to compute and establish the geoid with the desired accuracy, the MSL was and still is used to approximate the geoid.

In the new approach, it is proposed to utilize the geoid as the zero surface for the global vertical datum for use over land and in nautical charts and also to reference all bathymetric data to it. This referencing will then provide a time-independent and globally consistent definition and facilitate easy integration of different data sets which would originate either from adjustment of old observations with geoid as the new zero or transformation of local vertical datums. All new data surveyed and reduced under the new definition would be straight forward.

Another important point, which requires clarification under the proposed concept, is that the geoid (to be used) is defined by the following equation:

$$W(X,Y,Z) = W_0 \qquad (1)$$

where the "W" is the earth's total gravity potential and "W_0" the geoid constant as specified by the International Association of Geodesy (Moritz, 1980).

DEFINING TIME-INVARIANT ZERO REFERENCE SURFACE

Using the latest theoretical corrections/research and globally extensive gravity, altimeter, and satellite data sets, a new geoid model has now been computed by National Imagery and Mapping Agency (NIMA) and National Aeronautics and Space Administration (NASA). It is now available with estimated absolute accuracy of about ±25 cm over the oceans and between ±50 cm to 1 m over the land areas.

The lower accuracy values pertain to remote land areas and/or mountainous terrain where available gravity is not satisfactory in coverage, quality, and density.From a practical stand point, it is also obvious that the lower accuracy levels should not be critical over all these areas.

GEOID COMPUTATIONAL CONSTRAINTS

The computational task of such a high absolute accuracy geoidal solution using extensive data sets with coverage from all over the globe would be a very costly and time consuming effort. More so, the global solution to improve absolute accuracy is also not easily derived and the "significant" improvement in the data required for attempting the next global solution is NOT that simple.

To eliminate conflicts between too many zero surfaces, the use of regional geoids will have to be avoided and to ensure globally consistent absolute accuracy, proliferation of too many "local" solutions must be avoided. To achieve these goals, international institutions/organizations like the International Hydrographic Organization, International Maritime Organization, International Commission on Geoid, International Geoid Service, and International Federation of Surveyors, must play an important role in coordination and adoption of one accurate global geoidal solution by all users.

However, countries can try to develop high resolution relative local or regional geoids with a fit to the global geoid.

SURVEYING CONSISTENT BATHYMETRY

Figure 2 illustrates a typical survey scenario using GPS. In open and deep ocean areas, where accuracy of measured depths will be less critical, the ellipsoidal height (h) of the ship can be determined with GPS in navigation or single point positioning mode. As the survey scenario would approach the coast with shallower water depths, high accuracy requirements would also become more critical. In such cases, the ship's ellipsoidal height (h) would be established or surveyed with differential GPS technique where the survey can be designed to achieve desired higher accuracies in "h".

The surveyed ellipsoidal heights (h) of the ship can provide the hp of the sea surface, which when combined with the computed geoidal height (N_p), would give the orthometric height (H_p) as:

$$H_p = h_p - N_p \qquad (2)$$

Then, at the same epoch, the ship measures through sounding the distance S_p. Combining the S_p with sea surface orthometric height H_p (using equation 2), the depth D_p can be computed as:

$$D_p = S_p - H_p \qquad (3)$$

While the surveyed h_p and S_p and computed H_p would be time variant with the moving sea surface, the geoidal height (N_p) and computed depth (D_p) would be time-independent. Further, as the heights h_p and N_p would be established in the globally consistent World Geodetic System (WGS) 1984 used by GPS, the computed depth D_p through ship's soundings would also be defined with respect to the WGS 84 geoid (DMA, 1991).

Once an area is surveyed with all the depths referenced to the new WGS 84 geoid, the information can be utilized to contour the nautical charts. The data can also be stored as individual depths in a digital data base and will also be available for use with digital charts.

RECOVERING DEPTH AND HEIGHT CLEARANCES DURING NAVIGATION

a. Depth Clearance :

While navigating in an area with its nautical chart plotted and contoured for depths (Section 3.), the height (H_p), using the GPS surveys and the computed geoidal height (N_p), depth (D_p) and the ship's hulk (HL) are configured in Figure 3.

A measure of depth clearance (or the safe distance between the ship's bottom and the seafloor) will then be given as :

$$HL < H_p + D_p \qquad (4)$$

A new measurement of sounding (S_p) at the sailing time will then provide a check on the plotted depth D_p on the chart.

b. Height Clearance :

While navigating in an area with its nautical chart ploted for height clerance, the height (H_p), using the GPS surveys and the computed geoidal height (N_p), the height (H_p) of a bridge and length of the ship's mast (HM) are configured in Figure 4.

A measure of height clearance (or the separation between the highest point of the ship's mast and the bridge bottom) will then be given as :

$$HM < H_B - H_P \quad (5)$$

It is important to point out that the distance from the sea surface to the GPS antenna would be a measured correction in all of the above relationships.

RELATING THE TIDAL SURFACES

At any tidal station, the absolute zero of the tidal staff can be established by a GPS absolute point positioning survey at a nearby station and differential spirit leveling to the tidal staff (Figure 5). Its orthometric height H (≈ h - N) set to the geoidal zero will be consistent all over the globe.

Then, all the tidal surfaces, e.g., MLLW, MLW, MSL, MHW, can be surveyed with respect to the zero of the tidal staff or to the geoid and used with consistent definition worldwide as auxiliary information with the time-invariant bathymetry.

Though the tidal surfaces be tied to the same zero surface as the depths, it is emphasized that the tidal measurements and/or any reductions with respect to them would not be required for depth determination during navigating with GPS. In this mode, the ship navigator would use the high tide information as auxiliary data to compute the "safe" time when the high tide would improve ship's clearance to entering the shallower areas.

EVALUATING THE NEW CONCEPT

The proposed use of the geoid as the zero reference for a global vertical datum will enable us to integrate and analyze the depth and elevation data over the sea and land interface. It will also eliminate the numerous existing local tidal datums which are in use around the world.

However, the adoption of a new vertical datum would raise an immediate issue of what to do with the existing data sets based on the numerous MSLs and tidal surfaces based land and chart datums. Each of these datums, with its own definition, has valuable data and observational sets. Questions would arise over what to do and how to save all this valuable information.

One solution for the integration of the existing data sets is datum transformations but this method would not improve the quality and accuracy of the data based on the numerous tidal and chart datums. However, it would definitely help in utilizing the existing information until the new and more accurate data sets are surveyed and integrated under consistent, time-invariant, and accurate definition.

In case of land datums, a new solution using the old existing spirit leveling and new differential GPS data sets would be a good solution. It will then provide accurate and consistent elevations.

It is also noted that the proposed method to determine the depths with respect to the geoid also involves the sounding data and the accuracy of final results would require accurate acoustic modeling. As the issue concerning the accuracy of the soundings is not a new one, the improvement in the acoustic modeling should be considered as an area for future research (Section 6).

The revision of all existing paper charts and maps to reflect a global vertical datum is not viewed as a feasible and economical alternative; however, development of accurate digital terrain model and bathymetric data base, and adjustment of digital nautical chart and geospatial land information to a globally consistent vertical datum should be a reasonable option.

ACCURACY ESTIMATION

In Figure 2, in offshore areas the ellipsoid height (h) can be surveyed using differential GPS with an accuracy of $\pm$ 1 meter with respect to land control points in routine field surveys. Also, the current achievable accuracy of the geoid over ocean areas would be within the desired range of about $\pm$ 25 cm.

The above two estimates shift the emphasis to the sounding measurements and their surveyed accuracy which would impact the final accuracy of the bathymetric data. Table 2, extracted from a National Oceanic and Atmospheric Administration publication (NOAA, 1978), is one such example which specifies the accuracy standards for measurement of soundings during field surveys. Another very important document, which specifies international standards and classification criteria for hydrographic surveys and soundings, is the IHO Special Publication No. 44 (IHO, 1987).

Though the above table or the IHO publication specifies the desired accuracy requirements, standards, and classifications for soundings and related hydrographic surveys, the users would still be concerned about the accuracy actually achieved and/or obtained during any marine field survey over an area, especially when one would consider all the rapidly varying environmental conditions and use of different definitions. Thus, under the newly modified and more accurate survey scenarios with GPS techniques, the new concept of using a global geoid as zero vertical reference would be very timely. Further, the measuring of ship's soundings with modern instrumentation, a complete revision of achievable accuracies and specifications for the GPS and marine surveys and soundings, and setting of new international standards would also become an immediate necessity.

CONCLUSION

The practical complexity and difficulties arising from the use of numerous vertical datums and various time-dependent tidal surfaces with inconsistent definitions are impeding the correct integration of valuable information. This also affects safe navigation over international waters.

The new concept of the geoid as the zero reference surface for the time-invariant bathymetry and elevations is practical and also realizable with sufficient accuracy using current technology and available data sets. The computation of a modern global geoid with an absolute accuracy of $\pm$ 25 cm

is a costly project, but to accomplish the same at this time would be very timely. Problems arising from use of various relative and regional solutions and also of different global geoids with lower accuracies would have to be avoided. Use of local geodetic datums for differential GPS surveys would be another dangerous and critical problem. If the new survey data is not properly coordinated and collected under standar lized specifications, the present complexity may crop up in a different form.

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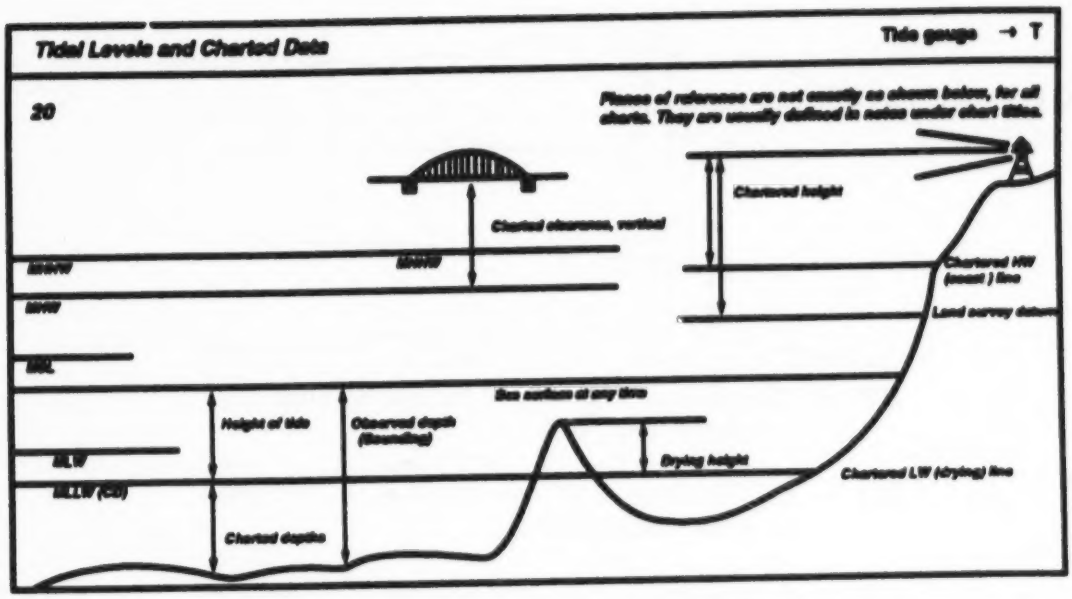

Figure 1. Tide Levels and Charted Data (NOAA, 1990)

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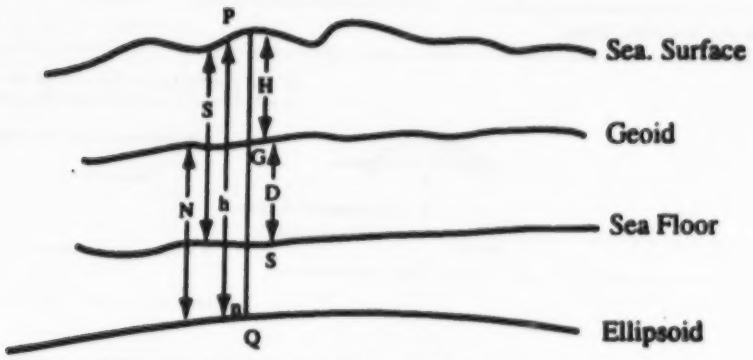

PQ = Ellipsoidal height (h) of the survey ship surveyed with GPS

GQ = Geoidal height (N) computed with the Earth Gravity Model (EGM)

PS = Sounding (S) measured acoustically from the survey ship

GS = Depth of sea floor (D) from the geoid

Figure 2. Surveying the Time-Invariant Bathymetry

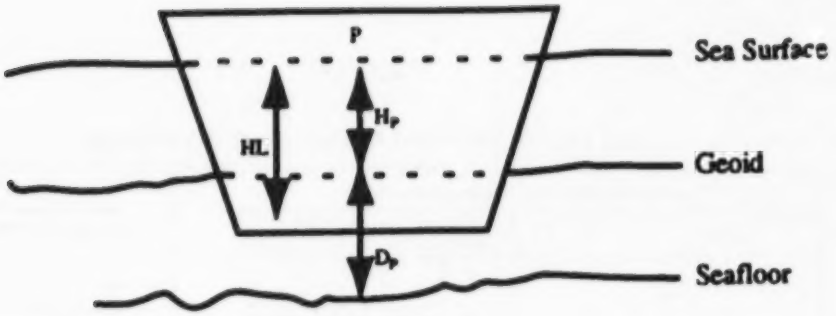

Figure 3. Surveying the Depth Clearance

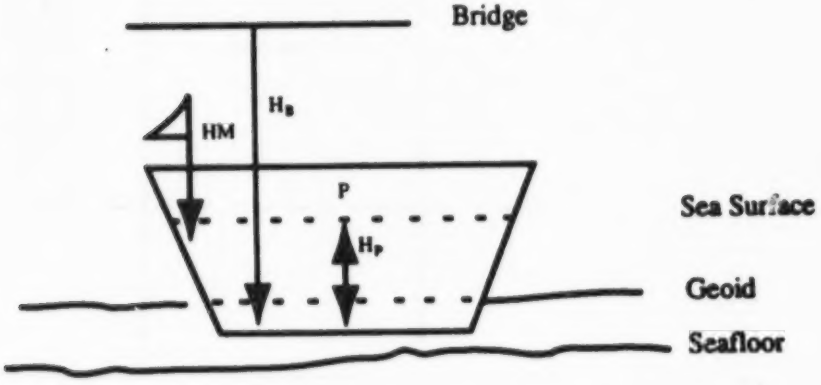

Figure 4. Surveying the Height Clearance

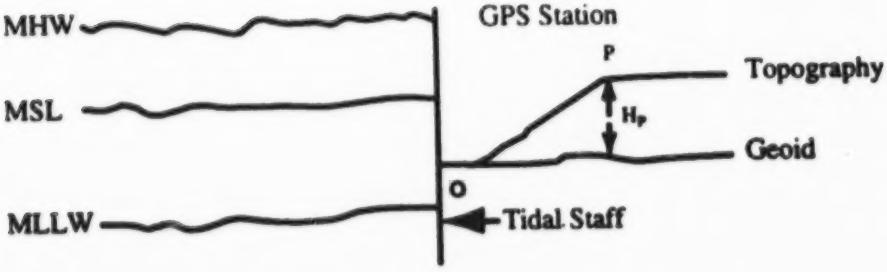

Figure 5. Surveying the Zero Height of the Tidal Staff

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Table 1[1]

Tide Tables Referred to Datum of Soundings

30	Tidal Levels referred to Datum of Soundings Place | Lat N | Long E | Heights in metres above datum (MHWS, MHWN, MLWN, MLWS; MHWS, MLHW, MHLW, MLLW)		Tabular statement of semi-diurnal or diurnal tides Note: The order of the columns of levels will be the same as that used in national tables of tidal predictions.
31		Tidal Streams	Tidal streams referred to: Hours | Geographical Position Time of High Water (Dover) | Direction of stream (degrees) | Rates at spring tides (knots) Time of High Water (Dover) | Rates at neap tides (knots)

1 NOAA, 1990.

Table 2[1]

Accuracy Standards for Soundings

Water Depth	Allowable Errors
0 - 20 meter	0.3 meter
20 - 100 meter	1 meter
> 100 meter	1% depth

1 Extracted from NOAA, 1978.